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Design and Implementation of a Consolidated Airfield at McMurdo, Antarctica

Robert Haehnel, Margaret A. Knuth, Terry Melendy, Christopher Hiemstra, and Robert Davis

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Abstract

This report presents a consolidated airfield design for McMurdo, Antarctica. The design includes a single skiway for ski-equipped aircraft and a single runway for wheeled aircraft. Two possible locations for the new airfield are on glacial ice at the current Pegasus site or on a snow surface 4–5 miles NE of Pegasus. Final decision on the location requires balancing the need to locate the airfield outside the dust plume against the ability to establish on a snow surface a runway that supports wheeled aircraft. The current whiteout landing area would still serve the needs of the consolidated airfield; and Williams Field would continue to act as an emergency divert site for ski-equipped aircraft.

A review of the runway support facilities shows that the number of buildings can be reduced from 27 to 14, reducing the size of the town site and the travel distance between functional elements.

The consolidated airfield, including support equipment and facilities, will take about seven years to complete. When complete, it will improve operational efficiency by consolidating services at a single location, eliminating movement of resources between two or more airfields, and allowing replacement of existing runway support buildings with more energy- and space-efficient designs.

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Preface

This study was conducted for the National Science Foundation (NSF), Division of Polar Programs (PLR), Antarctic Infrastructure and Logistics (AIL), under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-AIL-13-10, “NSF EP-AIL 13-10: McMurdo Consolidated Airfields, Phase II: Airfield Design Recommendations.” The technical monitor was George Blaisdell, Chief Program Manager, NSF-PLR, U.S. Antarctic Program.

The work was performed by Dr. Robert Haehnel and Dr. Christopher Hiemstra (Terrestrial and Cryospheric Sciences Branch, Dr. John Weatherly, Chief), Margaret Knuth* and Terry Melendy (Force Projection and Sustainment Branch, Dr. Edel Cortez, Chief), and Dr. Robert Davis (Director), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. Justin Berman was Chief of the Research and Engineering Division. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen.

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The Commander of ERDC is COL Jeffrey R. Eckstein, and the Director of ERDC is Dr. Jeffery P. Holland.

* Current affiliation: NSF-PLR.

Acronyms and Abbreviations

AGE	Aircraft Ground Equipment
AIL	Antarctic Infrastructure and Logistics
AMC	Air Mobility Command
AMP	Airfield Master Plan
AMPS-WRF	Antarctic Mesoscale Prediction System Weather Research and Forecasting Model
ANG	Air National Guard
ARFF	Aircraft Rescue and Fire Fighting
ASC	Antarctic Support Contract
ATCT	Air Traffic Control Tower
ATO	Airfield Transport Office
AWS	Automatic Weather Station
BRP	Blue Ribbon Panel Review of U.S. Antarctic Operations
CRREL	US Army Cold Regions Research and Engineering Laboratory
CTK	Consolidated Tool Kit
DNF	Do Not Freeze
DNT	Do Not Thaw
ERDC	Engineer Research Development Center
ETL	Engineering Technical Letter
FE	Facilities Engineering
HEO	Heavy Equipment Operator
IACS	International Association of Cryospheric Sciences

IHP	International Hydrological Programme
IT	Information Technology
JATO	Jet-assisted take-off
KBA	Kenn Borek Air (current fixed wing contractor)
MAINBODY	Main Operational Season of Airlift Operations (typically from 1 October through late February)
MEDEVAC	Medical Evacuation
MLS	Microwave Landing System
MOC	Maintenance Operations Center
MRSF	Mobile Runway-Support Facilities
n.a.	Data Not Available
N/A	Measurements not taken
NAVAIDS	Navigational Aids
NSF	National Science Foundation
NYANG	New York Air National Guard 109th Airlift Wing
OPS	Office Of Public Safety
PAPI	Precision Approach Path Indicator
PAX	Passenger
PLR	Division of Polar Programs
REIL	Runway End Identifier Lights
RSP	Russian Snow Penetrometer
SOP	Standard Operating Procedure
SPAWAR	Space and Naval Warfare Systems Command
SSALR	Simplified Short Approach Lighting System with Runway Alignment Indicator Lights

TACAN	Tactical Air Navigation System
TERPS	Terminal Instrument Procedures
USAP	United States Antarctic Program
VGI	Vapor Gradient Index
VMF	Vehicle Maintenance Facility
WINFLY	Winter Fly-in (of equipment, supplies, and personnel to support the opening of McMurdo Station, usually taking place starting around 21 August)
WO	Whiteout
WWTP	Waste Water Treatment Plant

Unit Conversion Factors

Multiply	By	To Obtain
bars	100	kilopascals
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
pounds (force) per square inch	6.894757	kilopascals
square feet	0.09290304	square meters

1 Introduction

Air operations are a necessary part of supporting the scientific mission of the U.S. Antarctic Program (USAP). Historically, McMurdo, Antarctica, has had as many as three airfields operating at various times during the summer season: the Sea Ice Runway on McMurdo Sound and Williams Field and Pegasus Runway, both on the Ross Ice Shelf. Recently, the National Science Foundation (NSF) has considered consolidating air operations to a single airfield. Haehnel et al. (2013) showed that, based on recent experience with reducing three airfields to two, further consolidation to a single airfield is feasible. Though it is not clear that this consolidation will produce any cost savings, consolidating resources (e.g., Aircraft Rescue and Firefighting [ARFF]), buildings, and support personnel may improve efficiency and lead to cost savings in the long term.

Key metrics for a consolidated airfield are (Haehnel et al. 2013) that it needs

- to be open for wheeled aircraft in late August to support winter fly-in (WINFLY) of personnel and cargo to support the opening of McMurdo Station,
- to be open to wheeled and ski-equipped aircraft from approximately 1 October through 28 February (MAINBODY), and
- to support rapid airfield preparation for mid-winter medical evacuations (MEDEVACs).

We anticipate with airfield consolidation that the key stakeholders will not change. As is now the case, the NSF Division of Polar Programs (PLR) will provide overall program direction and will coordinate the efforts of the other supporting agencies and organizations. The support contractor, currently ASC (Antarctic Support Contract), will provide main logistical support. The Space and Naval Warfare Systems Command (SPAWAR) will continue to provide air traffic control and operation of the navigational aids (NAVAIDS), the Air Force (15th Wing, Hickam Air Force Base) will operate the C-17 transports, and the Air National Guard (ANG) (109th Airlift Wing NYANG) will operate the ski-equipped LC-130s used for South Pole and Antarctic camp science support.

As part of this effort to evaluate airfield consolidation, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) commissioned an Airfield Master Plan (AMP) in fall 2011 to determine the optimum configuration of a consolidated airfield, including orientation, location of the supporting town site, and connecting taxiways and aprons, and to provide an initial design of the town site at the airfield along with a proposed building consolidation according to functional similarity (Thuma and Gregory 2013).

Though the AMP is comprehensive in providing an overall design of the facilities for a consolidated airfield, it did not consider several factors. These include the following:

1. Airfield location
2. Design of the whiteout (WO) landing area needed for landing LC-130s in the event of persistent zero-visibility conditions in McMurdo
3. Detailed infrastructure issues that need to be resolved to provide a consolidated airfield (e.g., aircraft fuel supply and waste water handling)
4. Timeline for constructing a consolidated airfield
5. Annual timeline for airfield preparations and operation

In our effort, we provide a summary of the AMP in the overall context of a recommended consolidated airfield design that also addresses the key points enumerated above.

In Section 2, we discuss factors determining the location of the airfield. Section 3 provides the overall airfield configuration, including a summary of the recommendations from the AMP study. Section 4 provides an overview of remaining infrastructure issues that need to be resolved to move forward with a consolidated airfield design; and Section 5 provides a timeline for constructing the consolidated airfield, including resolution of key issues identified in Section 4, design and construction of runway support facilities, support equipment procurement and delivery, and construction of the airfield (runway, skiway, taxiways, aprons, etc.). In Section 6, we provide a draft schedule for airfield operations, including preparations for WINFLY and MAINBODY and operations needed to close-out the flight season. Section 7 provides conclusions and recommendations.

Though this effort started before the release of the USAP Blue Ribbon Panel (BRP) review (Augustine et al. 2012), the benefits of consolidating resources are consistent with the BRP recommended action 4.4-7 to make the Pegasus airfield more permanent and to evaluate the future use of the Williams Field and the Sea Ice Runway. As appropriate, in Sections 2 and 3, we discuss how our study addresses BRP action 4.4-7.

2 Location

Several factors affect the decision of where to locate a consolidated airfield. Of primary concern, the airfield needs to be located as close as is practical to McMurdo Station and to be on material that can be prepared and maintained with current methods to produce a hard surface that will support landing of wheeled aircraft. As discussed in Haehnel et al. (2013), locating the airfield on the Ross Ice shelf as close to McMurdo as practical yet in a region where the snow accumulation is relatively small, so that a hard surface can be obtained by establishing the runway directly on glacial ice or on a thin layer of snow that is compacted over the glacial ice, would satisfy these requirements. Establishing the airfield on an ice and snow surface imposes some additional requirements:

1. Adequate fresh, fine-grained snow must be available to annually cap the wheeled runway. This will increase surface albedo (the ratio of reflected radiation to incoming radiation) thereby reducing weakening of the runway from solar radiation.
2. It must be, as much as possible, out of the influence of the dust and dirt plume from Black Island. Dirt deposited on the runway and access roads can severely reduce surface albedo, causing runway failure, making the roads impassable for wheeled vehicles (lengthening transit time), and compromising skiway operations.

Owing to the thin snow cover over strong glacial ice at the current Pegasus airfield, this seems a promising location to establish a consolidated airfield at McMurdo. However, we must recognize that, because the ice shelf is moving approximately WSW at a rate of about 90 ft/yr, the current location of the white ice runway (the wheeled runway at Pegasus) is about 1/3 mile WSW of where it was when it was originally established in 1992–93 (see Appendix A). Furthermore, an analysis of satellite imagery of the area surrounding Pegasus (Appendix B) suggests that the flow of the ice shelf has moved the runway out of the zero ablation region on which it was originally established and into what is now a net ablation region. Consequently, to establish a consolidated airfield at Pegasus, the runway would actually need to be re-located east of the current location. This has been required on other parts of the ice shelf, for example, at Williams Field, which has

had to be occasionally moved due to the Ross Ice Shelf moving almost 350 ft/yr in that region.

Next, we discuss in detail several factors affecting where the new runway can be located. These include annual snow accumulation, subsurface snow and ice structure, susceptibility to dust accumulation, and weather.

2.1 Snow accumulation

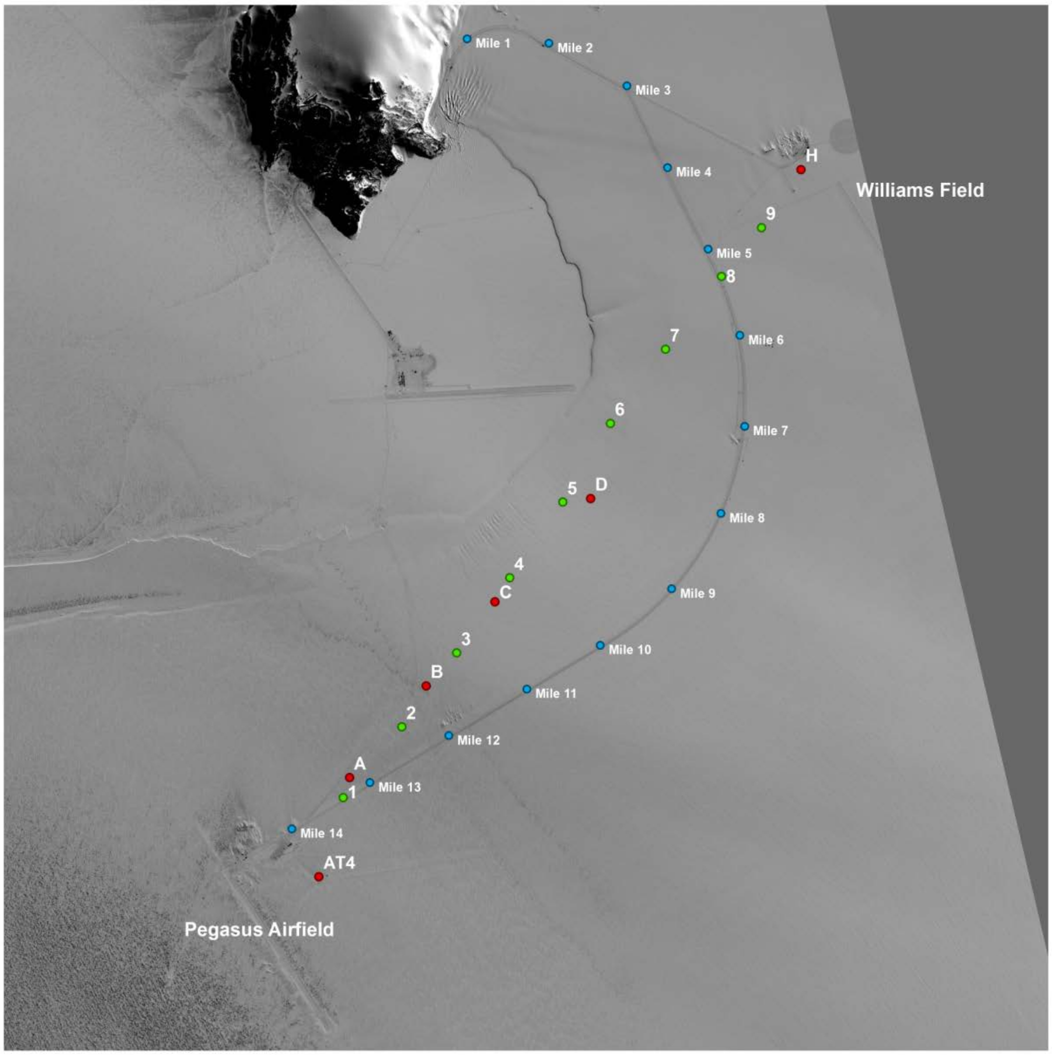
As discussed by Haehnel et al. (2013), the estimated optimal snow-depth accumulation rate for establishing a glacial runway is about 6 in. per year. This allows enough snow to “freshen” the runway and skiway surfaces throughout the flight season and to annually construct a compacted, high albedo snowcap on the runway (this is discussed in more detail in Section 4.1).

The spatial variation in snow accumulation between the Pegasus Airfield and Williams Field was observed in 1991–93 by Klokov and Diemand (1995) and more recently in 2009–12 by Haehnel et al. (2013) and Scanniello (2012). Figure 1 shows the locations of the observation points; Figure 2 provides a summary of the accumulation observed at these locations in terms of an average accumulation per year over the period of observation. We note that, in most cases, that period of observation was shorter than a year; to display all of the data on the same time basis, we normalized the accumulation by the fraction of the year over which the observations occurred. This treatment will tend to skew the data that was collected only during the winter to slightly higher values than the data that was collected for a full year as this projects the higher winter accumulation rate into the summer months. Yet, comparing the 1993 data set that has a sampling period of 1 year to the earlier data sets (with a shorter sampling period) indicates that this treatment does not appear to introduce significant error (winter-only data is, on average, about 10% higher than 1 year data, with a range of 4%–17% higher).

We note that the observations taken in the early 1990s (trend indicted by a solid line, Figure 2) indicate a more consistently higher accumulation rate than that in more recent history (dashed line, Figure 2). These observations indicate that, in recent years, there may have been a reduction of 3 to 4 in. of annual accumulation in the region that is 2 to 7 miles from Pegasus. This trend of less snow in recent years is consistent with anecdotal reports made by airfield operations personnel in the last couple of years that

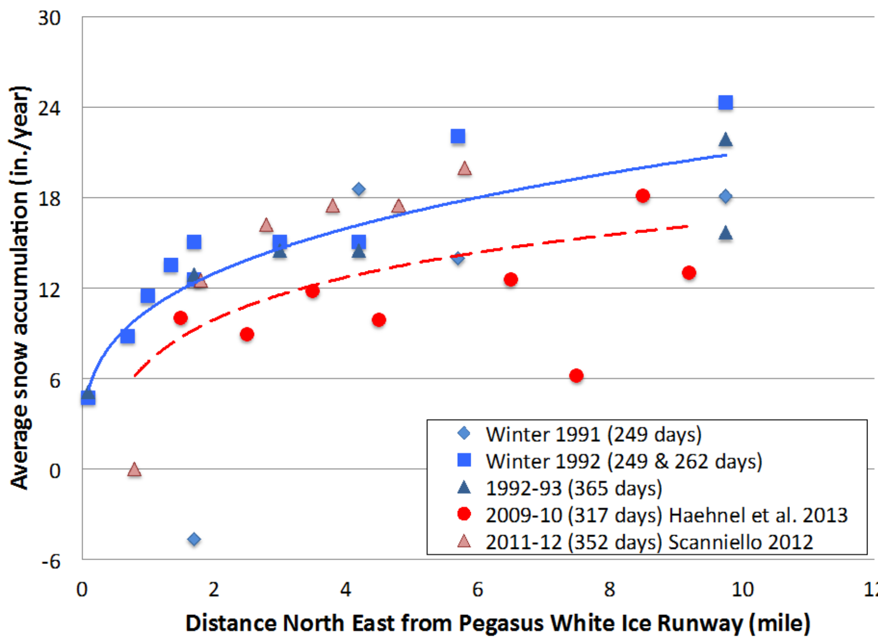
at Pegasus airfield there is generally less snow available for routine operations of constructing the snowcap on the runway and "freshening" up the surface of the runway and skiway.

Figure 1. Locations where snow accumulation and subsurface stratigraphy observations were made between Pegasus Airfield and Williams Field. The green dots indicate the location of observations taken during 2009–10 (Haehnel et al. 2013). The red dots are the approximate locations of observations made during 1991–93 (Klokov and Diemand 1995). The blue dots are the approximate locations of the data taken at road mile markers (Scanniello 2012).*



* Satellite imagery: WorldView-1, 31 October 2012. Longmont: CO, Digital Globe.

Figure 2. Observed snow accumulation at sites between the existing Pegasus Airfield and Williams Field (about 10 miles from Pegasus). The lines are least-squares fit through the data with the solid line indicating the trend for the data from 1991–93 (Klokov and Diemand 1995) and the dashed line for the 2009–13 data (Scanniello 2012; Haehnel et al. 2013). The legend indicates the period of observation; we note that, in most cases, the period of observation is shorter than a year. The data plotted for winter 1992 are for two sets of snow stakes with differing periods of observation; therefore, it provides the period of observation for each set. Direction given in the axis label is relative to true north.



2.2 Subsurface structure

In conjunction with the snow accumulation observations, during 1991–93 and 2009–10, Klokov and Diemand (1995) and Haehnel et al. (2013) also took cores at the same sites to determine variation in the subsurface stratigraphy of the snow and glacial ice between Pegasus and Williams Field. Figure 3 summarizes these results. The subsurface structure was characterized in terms of four ice forms: snow, hoar, firn, and ice. These broadly relate to the engineering properties and thus the status, availability, and proximity to the existing and potential airfield and relate to the preparation and maintenance of the airfield.

By way of definition, the term “snow” refers to the relatively fresh, fine-grained new deposits either accumulated during storms or during and after drifting events. Hoar or depth hoar crystals are larger, poorly bonded snow grains that form within the snowpack as a result of within-snowpack sublimation and vapor deposition onto larger grains (Fierz et al. 2009). Firn is “well-bonded and compacted snow that has survived [one or more

annual cycles], but has not been transformed to glacial ice. . . . Typical densities are 400–830 kg/m^3. . . . Thus firn is the intermediate stage between snow and glacial ice where the pore space is at least partially interconnected" (Fierz et al. 2009). Ice is obtained in the final stage of consolidation where "ice crystals [are] frozen together, with isolated pores and a density greater than 830 kg/m^3" (Colbeck et al. 1990). Ice has high compressive strengths, and the airfield mechanical preparation seeks to attain surfaces that approach ice in mechanical properties for the wheeled runway.

Strengthening of snow, hoar, and firn results from sintering, the growth of the cross-sectional area of bonds that form at contacts between grains. Sintering rates increase in proportion to temperature; the processes resulting in increased bonding become more active with greater temperature below the melting point. Snow with higher specific surface area* and finer textures sinters more rapidly than coarser firn and much coarser depth hoar.

Snow finds two uses, first as a high-albedo cap on the airfield, shielding the materials underneath from the weakening effects of solar radiation. Compacted snow also has moderate compressive strength, particularly after sintering. Because of its fine texture, snow sinters much more rapidly than the relatively coarser-grained firn and the much coarser-grained hoar. Well-sintered firn also has moderate compressive strength. As evidenced by the performance of the snowcap on the Pegasus runway we expect that both well-compacted snow and dense firn (densities for both greater than 550 kg/m^3) may provide sufficient compressive strength to support wheeled aircraft, provided that the snow and firn are founded on glacial ice or a thick† pavement layer is established. By contrast, hoar has low compressive strength; it also sinters quite slowly and, thus, is rather useless as an engineering material. Consequently near-surface pockets of hoar will likely need to be removed and replaced with a fine-grained snow that can be compacted and can sinter to form a strong "patch."

Figure 3 shows that less than 1 mile east of the existing white ice runway there is a rapid transition from near-surface glacial ice to firn. The depth

* Particle surface area divided by particle mass

† How thick this "pavement" layer needs to be to support wheeled aircraft when floating on a softer snow layer is the subject of ongoing research.

of snow is highly variable for observations that extend between about 0.7 and 6.5 miles northeast of Pegasus. The snow depth continues to increase further east, and at Williams Field the snow is nearly continuous at more than 5 ft deep.

To better understand the subsurface structure between the runway at Pegasus and the approximate location of AT4 (Figure 1), CRREL conducted a follow-up survey in December 2011. Figure 4 shows these results with the location where the ice cores were taken indicated by the darker blue circles. This figure shows that between location B and C, there is a rapid change in the depth to the ice or firn layer from approximately 5 in. at B to over 40 in. at location C. As indicated in Figure 3, we expect that over the ice or firn layer in this region is likely a mixture of snow and hoar similar to what is seen at AT4.

Figure 3. Subsurface structure of the snow pack on the Ross Ice Shelf at several locations between Pegasus and Williams Field. In addition to snow, hoar, ice, and firn, sand and soil particles were visible in some of the cores and are indicated by dots (•) in the diagram. Numbered locations are core samples reported in Haehnel et al. (2013); the remaining core samples were reported in Klokov and Diemand (1995). Figure 1 indicates the location of these samples with respect to each other.

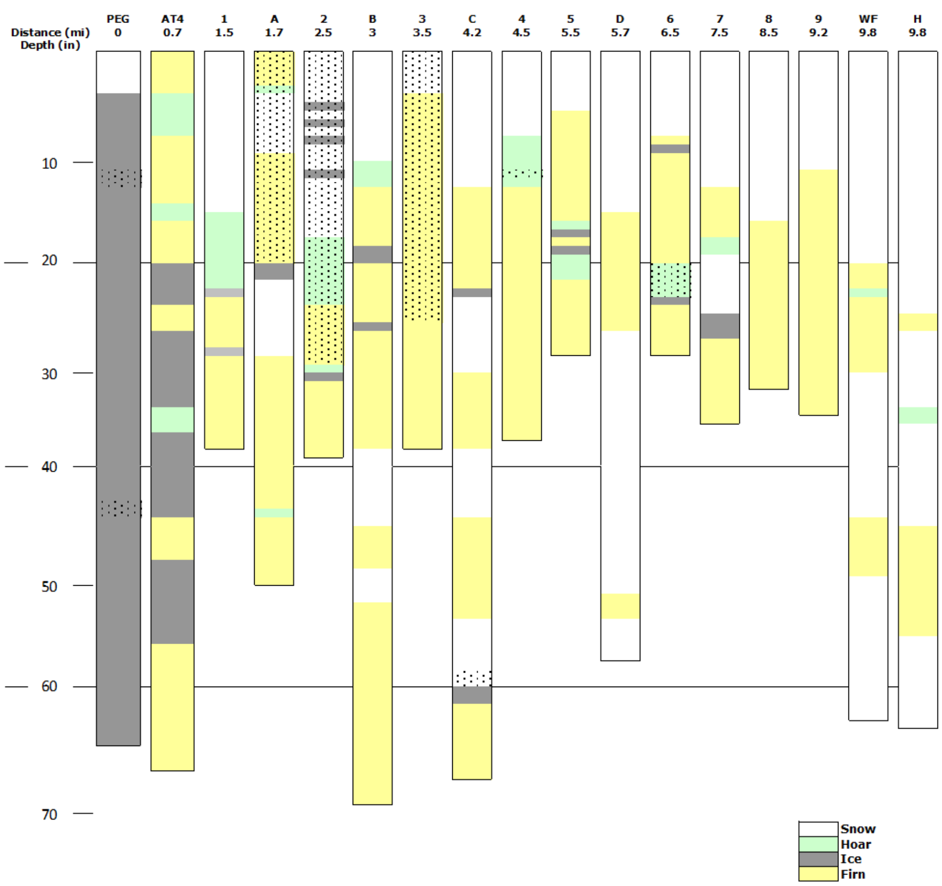
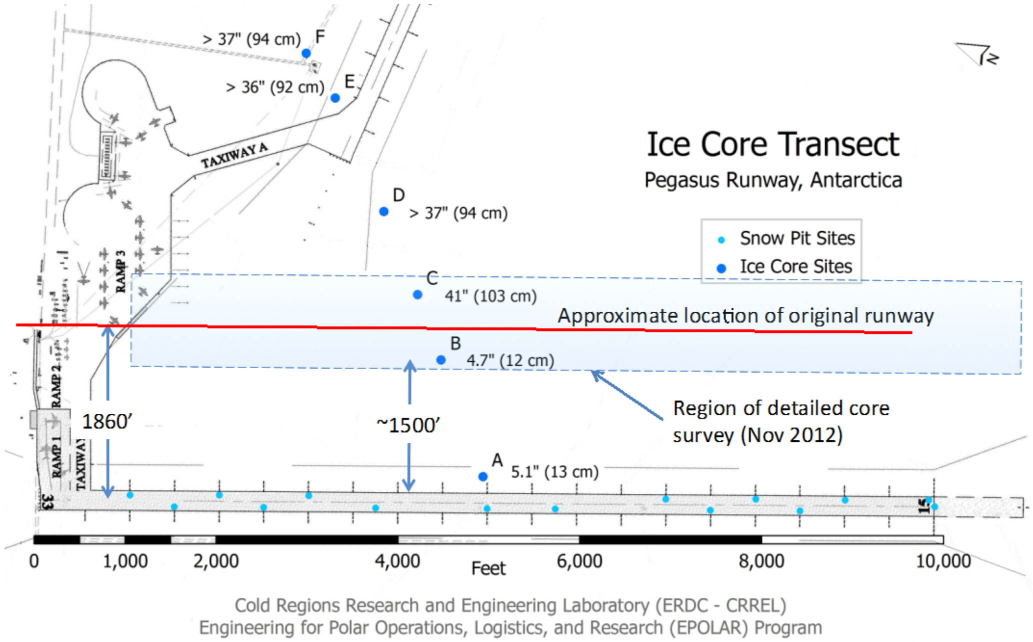


Figure 4. Locations of cores taken in December 2011 (dark blue circles) and November 2012 (dashed blue box). Measured depth to glacial ice or firn for each of the locations is noted beside each dark blue point (background image from Scanniello 2011a).



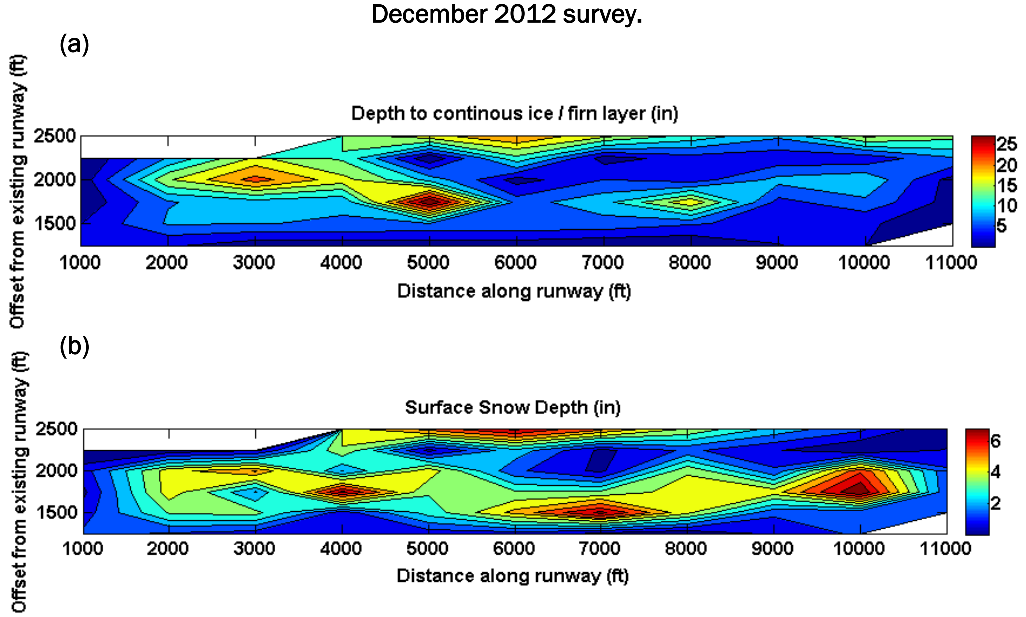
The approximate distance from the runway to point B in Figure 4 is 1500 ft, suggesting that much beyond 1500 ft east of the current location of the Pegasus runway the firm glacial ice is not close to the surface; and establishing a strong runway to support wheeled aircraft would require considerable effort. To further understand the spatial variation in the structure of the ice surrounding point B (Figure 4), CRREL conducted another survey parallel to the existing runway in the region enclosed by the box in Figure 4. The spacing of these cores was every 1000 ft parallel to the runway and every 250 ft perpendicular to the runway.

Figure 5 presents the results of this survey, conducted in November 2012, and shows that for a large fraction of the survey area, the ice or firn layer is within 5 in. of the surface (Figure 5a). However, there are some central locations within the survey region where the ice or firn surface is up to 2 ft below the surface. This is not surprising; when the original runway was established in 1991–92, there were regions where the ice needed to be patched to provide a continuous hard surface for wheeled aircraft operations (Blaisdell et al. 1998). We note that on the east edge of the survey region (2500 ft offset distance from the current runway), the depth to the ice or firn layer increases in relation to the bulk of the region surveyed. This may indicate the eastern extent of the near-surface ice or firn layer, confirming the observation at location C during December 2011. Furthermore,

it appears that as a general trend, the ice or firn layer is closer to the surface on the west edge (offset of 1250 ft in Figure 5a) while the ice or firn layer is deeper on the east edge.

There is not enough resolution in the data to determine definitively the orientation of the net zero ablation line within the survey region—or if it even falls within the survey area—and there may be some misalignment between the survey grid and that line. Judging from the geometry of the survey region (1250 × 11000 ft) and the general trend for increasing depth of the ice or firn layer proceeding from west to east, we assume that the misalignment cannot be more than a few degrees, however, and certainly less than 6°.

Figure 5. The (a) depth to firn or ice layer and (b) depth of surface snow measured during the December 2012 survey.



It is encouraging to also find that, in this region, the snow depth is shallow (typically less than 6 in.) (Figure 5b). This should allow for rapid clearing of the runway in preparation for WINFLY. Still, a moderate snow supply is required to annually re-establish a snowcap on the runway. Because this survey area is still very close to the location of the current Pegasus runway, we assume that an adequate (if not abundant) snow supply is available to support cap construction.

2.3 Dirt plume

The effect of dirt transported from the region of Black Island by the wind can have a profound effect on the performance of the airfield. This was ev-

idenced through the 2012–13 summer season wherein a large amount of dirt (size range of 0.074–2 mm) was blown onto the Pegasus airfield and roads east of the airfield, and the melting of the runway and skiway was so severe that the runway had to be closed for operations starting on 26 December 2012 and did not reopen until 11 February 2013*. Large melt pools formed at several locations along the length of the runway; so when it did reopen, only the east side of the runway could be used as a 90 ft wide tactical runway. Furthermore, the skiway became very soft, hampering flight operations for the LC-130 flights to South Pole and to inland camps. During this period, intercontinental flights were serviced with LC-130s, putting an additional strain on those resources.

Additionally, the access road to the airfield was affected. The road was so soft that, for a period of time, wheeled vehicles could not traffic the road between milepost 11 (see Figure 1) and the airfield, a distance of about 3.5 miles. During this time, wheeled vehicles were transported from milepost 11 to the airfield on large polyethylene sheets towed behind a tracked vehicle (these sheets are routinely used to transport fuel bladders, equipment, and cargo overland from McMurdo to South Pole). During the warmest period, the wheeled vehicles had to be ferried as far as milepost 7–8. The ferrying of vehicles across this "bog" further increased the transportation time between Pegasus Airfield and McMurdo. Also, during the time when this condition existed, the flight crews were transferred between McMurdo and Pegasus via helicopter†.

At no other time during the operation of the Pegasus runway has there been as severe melting as occurred during the 2012–13 season. The severe degradation of the airfield and connecting roads during the 2012–13 season are attributed to an unusually large amount of dark material deposited on the Ross Ice Shelf during early December of 2012. Additionally, this was the third warmest season on record‡ since the Pegasus Runway was established in the early 1990s. The fact that two other seasons were warmer on average than the 2012–13 season yet the runway remained operable suggests that the large amount of dirt deposited in the region was likely a

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* Gary Cardullo, Airfield Manager, Antarctic Support Contract, Centennial, CO. Personal communication, 12 March 2013.

† George Blaisdell, Chief Program Manager, NSF-PLR, Arlington, VA. Personal communication, March 2013.

‡ Based on a calculation of the accumulated thawing degree-days at Pegasus where a thawing degree-day is the product of the degrees above the freezing temperature and days at that temperature.

key factor. Consequently, it is desirable that the airfield be located outside the normal dirt plume if possible.

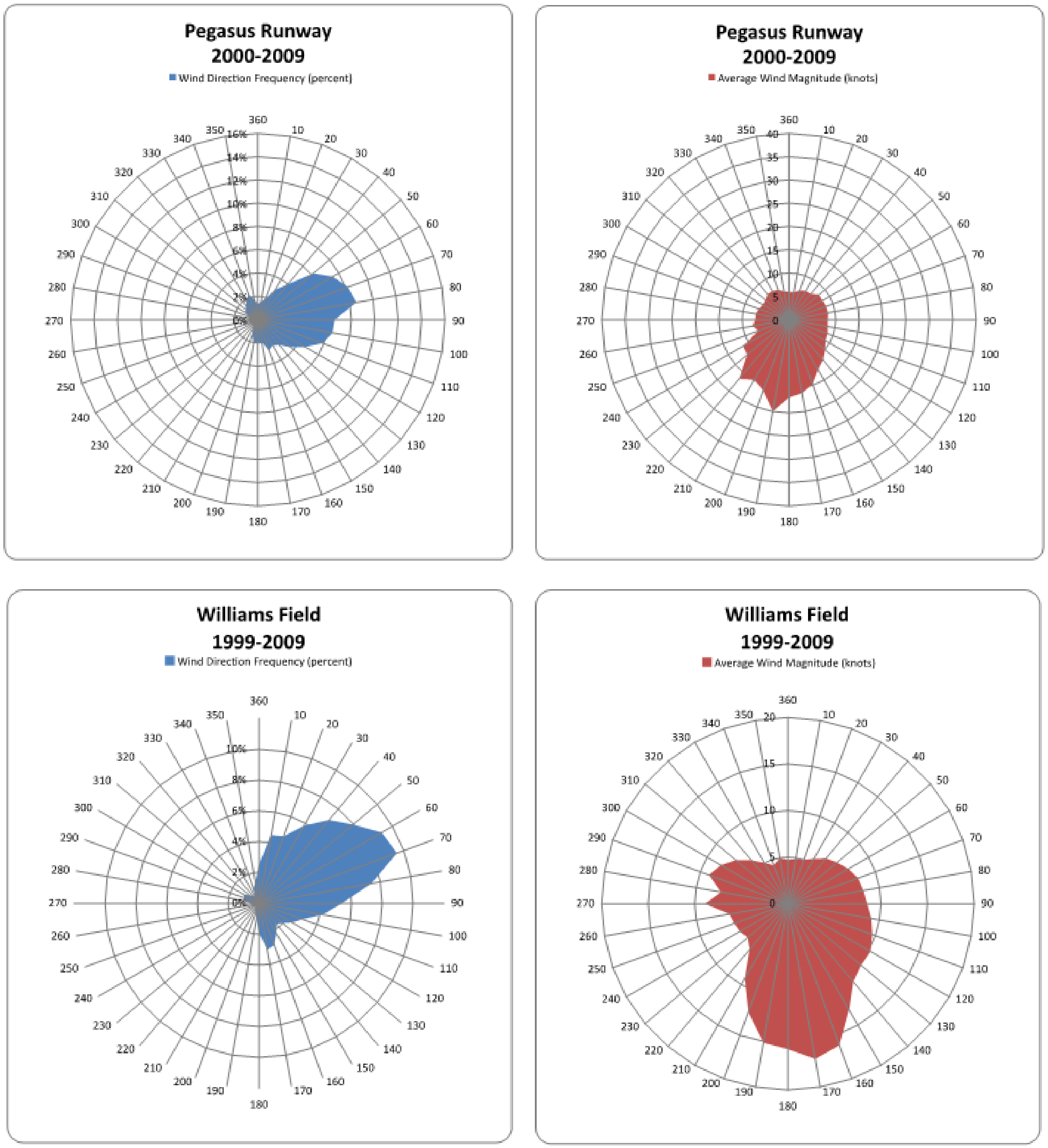
Based on the 2012–13 season, we find that the main influence of the dirt plume extended as far as milepost 11, about 3.5 miles NE east of the airfield. Additionally, Figure 3 shows particulate matter in the subsurface cores as far NE as 6.5 miles (core number 6), which corresponds to the furthest extent of the deteriorated roads in the warmest part of the 2012–13 season. Yet, in general, cores taken beyond 3.5 miles NE of the airfield (i.e., beyond core 3 in Figure 3) show little to no dirt in them, suggesting that east of milepost 11, the amount of dirt deposited on the ice shelf was small. We note that, based on the data presented in Figure 2, extending NE beyond milepost 11, the annual snow accumulation is 12–18 in. or greater.

2.4 Weather

The Antarctic Meteorological Research Center has monitored the weather at both Pegasus Airfield and Williams Field since the early 1990s*, and the differences in weather between these two sites are well understood. The temperatures at both locations are about the same; Haehnel at al. (2013) showed that, on average, the temperatures at Pegasus and Williams Field are 5.6°F and 6°F lower than at McMurdo Station, respectively. The main differences in these two locations are the wind and snow accumulation. As a general rule, the Pegasus location is windier than Williams Field. Figure 6 provides wind roses for both sites. We note the maximum winds at Pegasus are on the order 20 knots while at Williams Field the maximum wind speed is around 17 knots; the wind directions are very similar at both sites. The prevailing winds come from 70°–80° at Pegasus, and at Williams Field the prevailing winds are from 60°–70°. The storm winds at both sites come from a southerly direction with Pegasus at about 190° and Williams Field at 170°.

* The Antarctic Meteorological Research Center (https://amrc.ssec.wisc.edu/) has maintained nearly continuous weather records since 23 January 1990 at Pegasus and 25 January 1992 at Williams Field.

Figure 6. Wind data at Pegasus Airfield and Williams Field (data and charts provided by SPAWAR).



As previously discussed and as shown in Figure 2, the snow accumulation at Williams Field is typically 18–24 in. while at Pegasus the accumulation is less than 6 in.

Though close in proximity (about 7 miles separate these two sites) the weather at any given time can be very different. For example, localized fog may settle in on one location while leaving the other site clear.

No weather data has been recorded between Pegasus Airfield and Williams Field. If there is an interest in establishing a consolidated airfield somewhere in this region NE of the current Pegasus Airfield, an understanding of how the weather might vary due to local influences (e.g., proximity to White Island and Ross Island) is necessary. To help understand the variation in weather in this region, Manning and Powers (2011) conducted a study by using the Antarctic Mesoscale Prediction System Weather Research and Forecasting model (AMPS-WRF). This is a multi-grid model with the outer domain (45 km grid-cell resolution) covering the polar region and extending as far north as New Zealand and the southern tip of South America. Nested grids of finer resolution encompass regions of interest, such as the South Pole and McMurdo. The grid resolution surrounding McMurdo is 1.67 km. A summary of the results obtained by Manning and Powers (2011) is provided next.

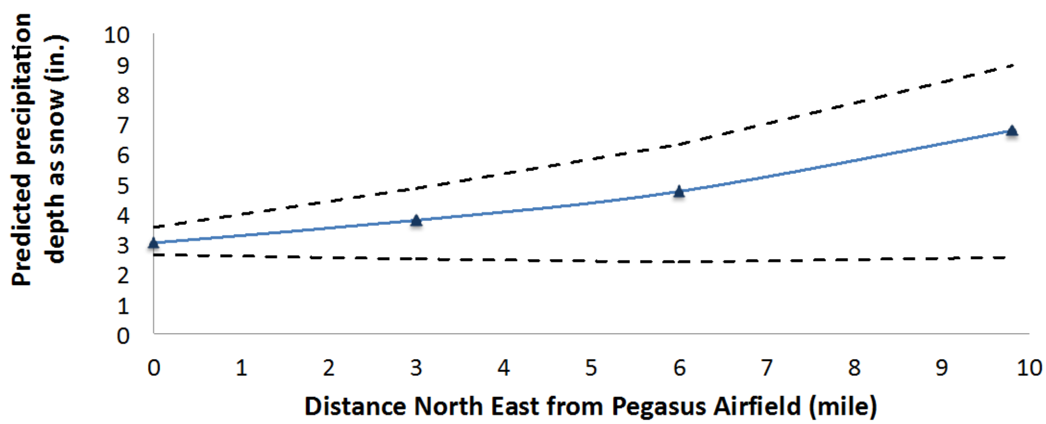
In addition to computing weather statistics for Pegasus and Williams Field, Manning and Powers (2011) computed for two sites between the two airfields by using AMPS-WRF. These sites were about 3 and 6 miles NE of Pegasus and were located along the line that extends between Pegasus and Williams Field; therefore, they are in the general proximity of locations B and D, respectively, in Figure 1.

Not surprisingly, the model results show that, in general, these intermediate locations are an average of the Pegasus and Williams Field sites. The wind magnitudes are a little lower than Pegasus and the wind directions (prevailing and storm) are similar to Pegasus and Williams Field. Similarly, the air temperatures are very close to those currently at the airfields.

In Figure 7, we show precipitation as snow depth. In this figure, the water equivalent precipitation amounts provided by Manning and Powers (2011) are converted to snow depth by assuming the ratio of windblown-snow depth to water equivalent precipitation is 3.6:1 (Sturm et al. 2010). (For fresh fallen snow, a more typical ratio is 10:1; however, the density of the fallen snow is increased when blown by wind.) The precipitation amounts shown depict a similar trend to the snow accumulation data presented in Figure 2. However, the accumulated snow averaged over the year drops off more steeply near Pegasus than the trends in precipitation show in Figure 7. This is likely because of redistribution of the snow by wind and loss due to sublimation; snow may fall at Pegasus, but it may be blown or ablated so that the net accumulation is smaller than the precipitation amount.

Similarly, a net deposition from blowing snow in the region surrounding Williams Field will elevate the measured snow accumulation over that predicted based on precipitation amounts alone. We also note that the variability in precipitation increases going from Pegasus to Williams Field.

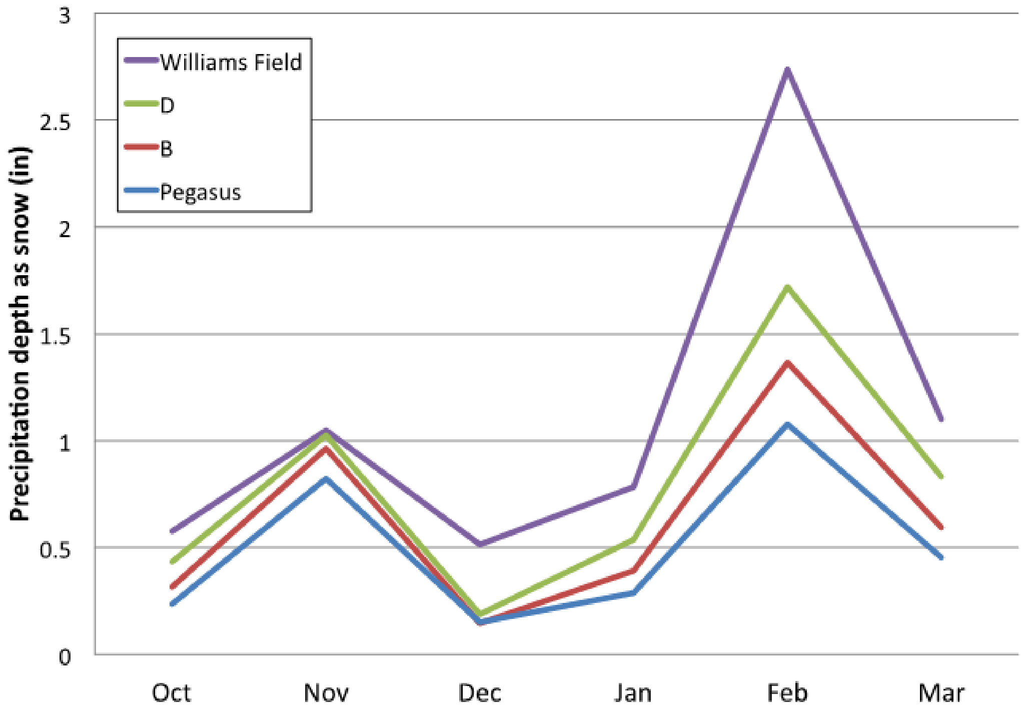
Figure 7. Predicted average precipitation as snow depth between Pegasus Airfield and Williams Field for the period extending from October to March (Manning and Powers 2011). The solid line indicates the average of three years (October 2008–March 2011) while the dashed lines indicate the range in predicted precipitation over the same 3-year period. The water-equivalent-precipitation depth is converted to snow depth by assuming a windblown-snow depth to water-equivalent of 3.6:1. Direction given in the axis label is relative to true north.



In Figure 8, we show the variation in precipitation by month. The largest snowfall for all locations is in February. Based on the model data, however, the monthly accumulations for B and Pegasus are generally less than 1 in. with precipitation increasing towards Williams Field.

Overall, we expect that wind speeds and direction between Pegasus and Williams Field will differ only slightly from those seen at either airfield, with winds diminishing moderately in magnitude moving from Pegasus to the NE. Likewise the temperatures do not differ significantly from those seen at either existing airfield. Precipitation amounts increase moving from Pegasus to Williams Field, with the amount of precipitation at Williams Field nearly double that seen at Pegasus. Based on the AMPS-WRF forecast model, average monthly snow precipitation totals during the flight operations season are typically less than 4 in. for Pegasus and the alternate site B. Even at the alternate site D (about 6 miles east of Pegasus) the average monthly totals are typically less than 5 in.

Figure 8. Predicted precipitation as snow depth by month through the operational season (Manning and Powers 2011). The water equivalent precipitation depth is converted to snow depth by assuming a windblown-snow depth to water equivalent of 3.6:1. The intermediate prediction locations approximately correspond to locations B and D in Figure 1 and are therefore labeled accordingly.



2.5 Summary

Based on the availability of near-surface glacial ice or firn necessary to provide a hard surface for landing a wheeled aircraft, we find that the furthest east one could locate a consolidated airfield is about 2000 ft from the location of the current white ice runway (see Figures 3–5). Yet, considering the severe melting brought on by dust deposited on the ice shelf during December 2012, it may be prudent to consider locating the consolidated airfield near milepost 10 (4–5 miles NE of Pegasus, see Figure 1), outside of the main influence of the dust plume from Black Island. This would require establishing the airfield on a softer base of aged snow rather than hard ice and firn and will require construction of an initial snow pavement that will support wheeled flight and will provide a firm base from which to maintain a compacted surface over subsequent years. Establishing and maintaining a snow pavement strong enough to support wheeled aircraft may be the biggest obstacle to siting the consolidated airfield at this location.

Because the snowfall and yearly snow accumulation increase the further NE one goes (Figures 2 and 7), locating at milepost 10 will also keep to a minimum the amount of snow that needs to be cleared in preparation for WINFLY and following storms during the operational season. In this region near mile 10, the annual snow accumulation is approximately 12–18 in. (Figure 2). Based on the AMPS-WRF model, approximately 4 in. of that total will come during the operational season with approximately 1.5 in. in February (Figures 7 and 8). Thus, we expect on the order of 8–14 in. of accumulated snow during the winter months will need to be processed (removed or compacted) prior to WINFLY. These totals are appreciably more than what Pegasus experiences but may still be manageable, assuming a hard surface that can support wheeled aircraft can be established by compacting and sintering the snow into a pavement, as this region lacks near surface glacial ice.

We also must address the suitability of the location for rapid preparation of the airfield for WINFLY and mid-winter MEDEVAC flights. The current Pegasus runway can be quickly prepared for use by clearing 4–6 in. of accumulated snow to expose the hard glacial ice surface. At milepost 10, there is no near-surface glacial ice; and winter snow accumulations is greater. At this site, we must consider whether adequate resources are available throughout the winter to maintain a strong compacted runway surface that will support wheeled flights as snow accumulates from drifting and precipitation during winter. If this is not possible, carrying out mid-winter MEDEVAC and possibly WINFLY operations may require ski-equipped aircraft.

From a flight operations point of view, lower winds near milepost 10 (in comparison to Pegasus) and only slight variation in wind direction should allow maintaining approximately the same approach headings as what is currently used at Pegasus and Williams Field. However, SPAWAR must perform a terminal instrument procedures (TERPS) analysis at the proposed sites to verify if these locations would provide acceptable approach clearances for establishing an airfield. For example, the current Pegasus runway is oriented such that it is aligned with the gap between Black and White Islands. Moving the Airfield east of the present location may result in having White Island in line with the approach to the runway, complicating the approach avenue.

We note that proper siting of the consolidated airfield is critical to addressing BRP action 4.4-7 (Augustine et al. 2012) by establishing the consolidated airfield in a stable location that supports uninterrupted operations in the long-term. This may not mean that we make the Pegasus airfield more permanent as the BRP recommends but rather that we establish a consolidated airfield in a location that is more “permanent” than what can be achieved at the Pegasus site.

3 Configuration

A consolidated airfield would be composed of several components including the airside facilities (runway, skiway, WO landing area, NAVAIDS, Air traffic control tower [ATCT], and markers and lights to support those facilities), landside facilities (a town site that supports cargo handling and passengers), and access roads. Thuma and Gregory (2013) recently completed an initial design of the layout of all but the WO landing area in their AMP. Below, we provide a summary of the design and recommendations for the consolidated airfield and WO landing area.

3.1 Runway and skiway layout

The planned layout of the runway and skiway for the consolidated airfield differs only slightly from that of the existing Pegasus airfield. Figure 9 shows airfield layout recommended by the AMP. It consists of a white ice runway for wheeled aircraft that is oriented approximately N–S and a skiway that is oriented approximately W–E. Between the runway and skiway are the aprons; taxiways; fuel pits; parking locations; and town site that provides cargo handling, a passenger (PAX) terminal, and other support facilities. We will defer further discussion of the town site to Section 3.3 and will concentrate on the airside facilities presently.

A review of the Pegasus wind data by Thuma and Gregory (2013) showed that we could achieve a slight improvement in availability of the airfield by reorienting the runway and skiway. The current heading of the runway is 150°–330°, and the skiway heading is 80°–260°. (All headings are provided in the grid coordinate system*). This provides airfield access for the LC-130s, which have a 15-knot crosswind limit, for 98.43% of the winds experienced at Pegasus. The analysis showed that we could attain a slight improvement (98.74% wind coverage) with a runway heading of 170°–350° (20° clockwise from the current orientation) and a skiway heading of 70°–250° (10° counter clockwise from the current heading).

The marginal gain in wind coverage may not justify these changes in the runway heading. What may be of more concern is close alignment of the

* At McMurdo, the conversion from grid coordinates to true coordinates is true = grid − 167°.

runway with the net zero ablation zone if the runway for the consolidated airfield is established on the glacial ice. From the survey that Figure 5 summarizes, it is not definitive that the orientation of the current runway is aligned with the net zero ablation zone; and some variation of the runway orientation (less than ±6° as indicated in Section 2.2) may be acceptable. This taken together with the wind analysis, we recommend that if the runway is established on glacial ice near the current location of Pegasus, it be rotated no more than 5° clockwise from the current heading. Such a minor change would have very little effect on improving the wind coverage for LC-130s landing on the runway; therefore, we recommend that if located at the Pegasus site, the runway heading remain unchanged.

There is more flexibility in the orientation of the skiway as there is no need to align it with characteristics of the ice shelf, such as a net zero ablation line. Therefore, the AMP's recommended grid heading of 70°–250° may be acceptable and would improve the wind coverage on the skiway.

If the consolidated airfield is located near milepost 10, as discussed in Section 2.5, it is likely that the runway headings recommended in the AMP may be acceptable. However, if this site is considered, we recommend further reviewing the wind in this area to finalize the optimal runway and skiway headings when the final site selection is made.

Furthermore, the exact orientation of both the runway and skiway depend on other factors, such as favorable TERPS. Pending the TERPS analysis, Table 1 summarizes the recommended runway and skiway headings.

Table 1. Recommended runway and skiway headings for the consolidated airfield if located at the current Pegasus site or at milepost 10.

	Grid Heading (degrees)
Pegasus	
Runway	150–330
Skiway	70–250
Near milepost 10	
Runway	170–350
Skiway	70–250

The analysis by Thuma and Gregory (2013) also recommended slight modifications in the location of the ATCT and the NAVAIDS, such as the tacti-

cal air navigation system (TACAN), as indicated in Figure 9. These modifications were made to optimize the location of these facilities owing to the new runway orientations and the consolidation of infield area that encompasses the town site, aprons, aircraft parking, etc. (Thuma and Gregory 2013). Final locations of the NAVAIDS will be determined once the final decision regarding airfield location and runway and skiway orientation is made.

Figure 9 also shows the proposed location and layout of the taxiways; aprons; and aircraft parking and refueling, including jet-assisted take-off (JATO) storage and handling. Figure 10 shows a close-up view of this region along with an isometric view of the airfield layout. These figures include a few changes in the airfield configuration as compared to the current Pegasus airfield. They increase the number of fueling positions at the fuel pit from 4 to 6 while reducing the number of parking positions for LC-130 parking from 8 to 6. Furthermore, they reconfigure the C-17 apron and taxiway to allow side-by-side parking of two C-17s, preventing one aircraft from blocking another from exiting its parking position. These changes were made to improve the efficiency of aircraft and cargo movement by reducing travel distance and reducing the grooming effort through decreasing the area of the aprons, taxiways, etc. The proposed airfield layout provides almost a 16% reduction in groomed area—not including the runway and skiway—over the existing airfield. When the runway and skiway are included, the total groomed area is reduced by about 8.2% (Thuma and Gregory 2013).

Figure 9. Proposed layout of the McMurdo consolidated Airfield (Exhibit 8-6 from Thuma and Gregory 2013).

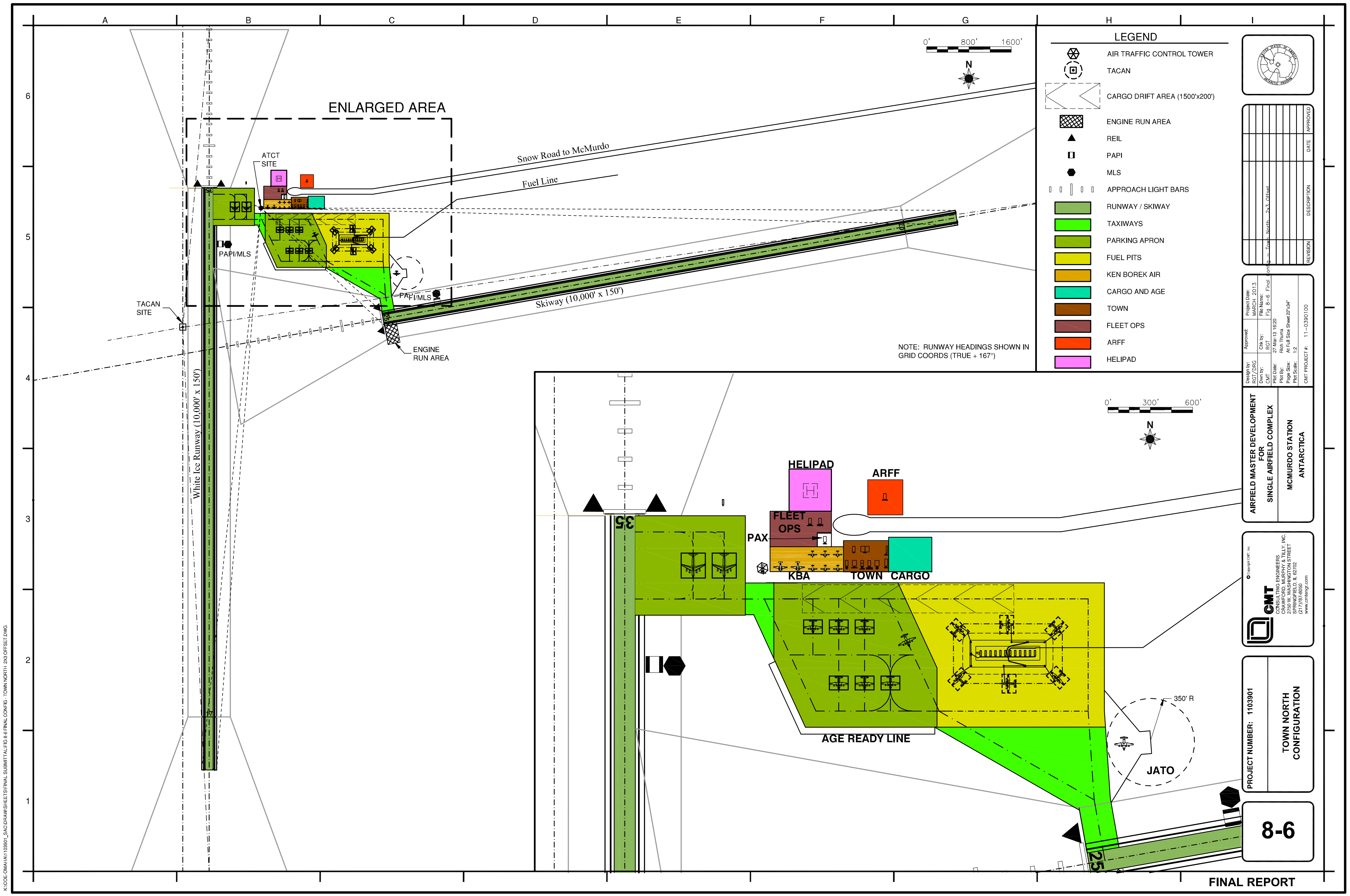
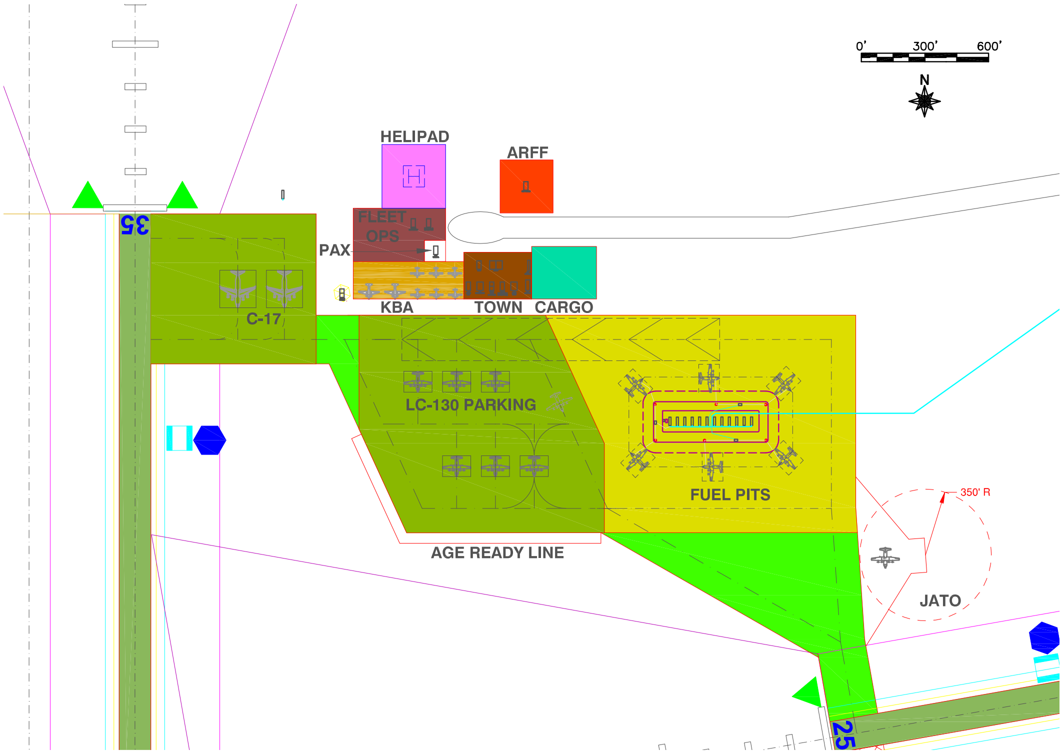


Figure 10. Plan view (top) (Thuma and Gregory 2013) and isometric view (bottom) (rendering courtesy of CMT Engineering, Springfield, IL) of the apron, taxiway, and town site area of the proposed consolidated airfield.



3.2 Whiteout landing area

Not included in the AMP is consideration for a WO landing area. Severe weather at McMurdo can occur quickly with little advance warning and may bring windblown snow or fog. These conditions can cause partial or complete WO conditions. Therefore, as briefly discussed in Section 1, in addition to maintaining the immediate airfield support facilities to provide for contingency operations, a WO landing area must be available. This is a large, flat area, free of obstructions, that allows the pilot to initiate a very gradual decent (100–200 ft/min descent rate*) in zero visibility, eventually touching down and coming to a stop within this "safe" zone. Currently, a WO landing area is maintained off the east end of Williams Field skiway 25 (heading 250°) in what is known as the Windless Bight area. This is a region where the snow has not been redistributed much from wind and therefore is very flat. Figure 11 shows the current location of the WO area; the extent of the WO landing area is indicated by the red sector. It is beaconed by using the TACAN for the existing Williams Field and is large enough to allow for many miles of relatively featureless terrain in which to touch down. The maneuvering areas flanking the WO landing area allow regions for the pilots to maneuver for cross-wind landing in the WO area without fear of encountering vertical obstructions in their flight path. The requirements for a WO area are outlined by NYANG (2011) (reproduced in Appendix C).

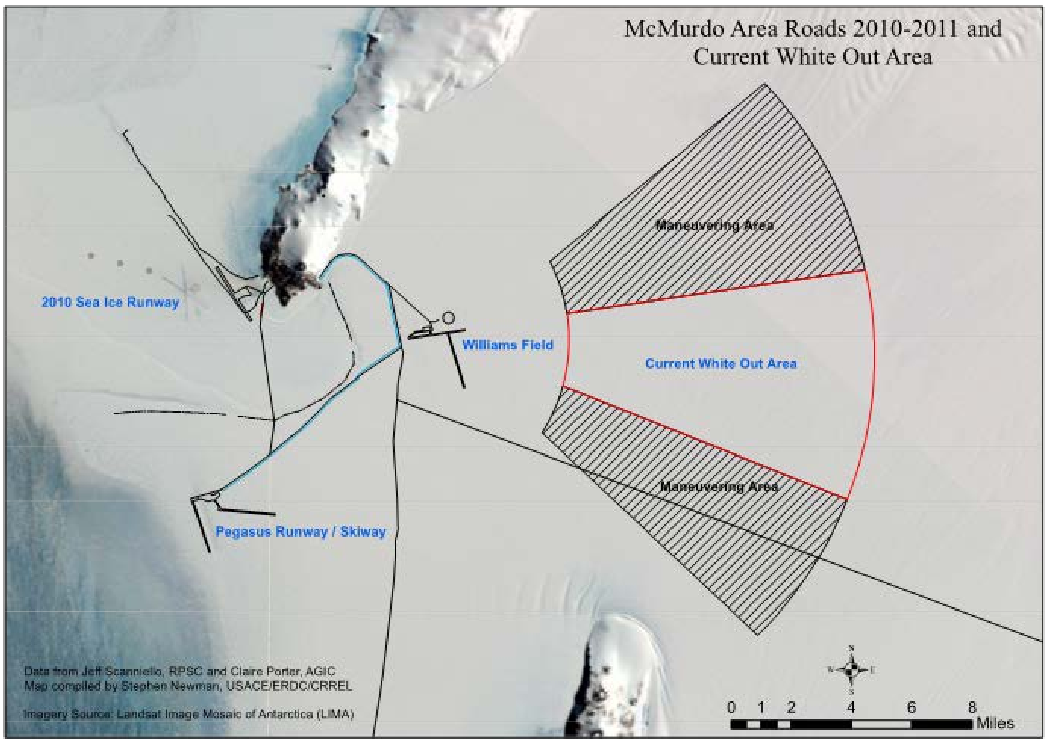
Considering the proposed locations of the consolidated airfield, the current WO area is remote; and aircraft using this would be far removed from recovery support in the event of a WO landing. For this reason it is desirable to locate the WO area closer to main airfield operations.

As part of this effort, we reviewed possible alternatives to the existing WO area shown in Figure 11; Appendix D provides the details of this review. We identified a possible alternative location for the WO landing area that places it about 2.3 miles closer to the planned location of the consolidated airfield than the existing WO area; however, it is debatable if there is any advantage to moving the current WO landing area. A TACAN will still need to be maintained at Williams Field as long as that airfield continues to serve as a weather-divert landing site for ski-equipped aircraft. Therefore we are unable to eliminate the need for two TACANs (one at the consoli-

* COL Gary James, NYANG. Personal communication, 29 December 2010.

dated airfield and a second at Williams Field). Second, for both designs (the existing and the alternative: option 3 discussed in Appendix D) the WO landing area is remote from the consolidated airfield, and a reduction in distance of about 2.3 miles is likely not sufficient on its own merit to justify a change. Therefore, for the present, we recommend that the WO landing area remain at its current location.

Figure 11. Sketch of the current WO landing area maintained to the east of Williams Field.



3.3 Town site

The airfield town site provides all major support functions to the airfield operations. This is set up in support of shift crews operating at the airfield, with billeting provided at McMurdo Station on Ross Island. Yet, it must be designed with sufficient consideration for temporary "sheltering" of personnel in the event of a weather event that prevents evacuation back to McMurdo.

The main functions the town site provides are (1) cargo and passenger handling, (2) air traffic control, and (3) ARFF.

The facilities required to support these functions and the shift crews that are on-site include the following:

- Cargo storage facilities and transport equipment
- PAX terminal
- ATAC
- Aircraft maintenance
- Office space for ANG, ASC, and Kenn Borek Air (KBA) (the current fixed wing contractor)
- Power generation and distribution
- Communication
- Food services and potable water
- Waste water handling

Presently, mobile runway-support facilities (MRSF) are available for housing these functions. These are relatively small buildings* on skis that are used at the various airfields and are moved between them to support operations at each while they are in use. Currently, 27 buildings are used to support airfield operations at Pegasus.

Consolidating all air operations to a single site largely eliminates the need for *mobile* support buildings. (Note that these buildings would likely still be on skis, much like the long-duration balloon facility, to allow them to be moved to winter berms but that travel over multiple miles would no longer be necessary.) This opens up the possibility of consolidating buildings, thereby reducing the size of the town site, providing more efficient operations (reducing walking and transport distance), and improving energy efficiency (e.g., reducing building surface area).

As part of the AMP, Thuma and Gregory (2013) reviewed the total space allocated to each function to determine how much space the site requires in comparison to what is currently used. Furthermore, they explored how to consolidate similar functions into a single building to improve efficiency of operations. From that study, they found that the number of buildings could be reduced from 27 to 14. Most of the proposed new buildings are 20 ft wide × 40 ft long and are one-story tall, yet several of the new buildings are two-story. The proposed ATCT is 2.5-story building, which allows visibility over all the other buildings and improves depth perception on the

* Typical building size is 12 ft wide × 32 ft long. Some buildings are larger, however, such as the PAX terminal (20 × 40 ft) and galley (45 × 60 ft). Two of the large buildings (ANG life support and the galley) are built up of several smaller modules that are taken apart to transport and are reassembled at the airfield. Thus, the total number of modules moved between the airfields is 30.

airfield for the controllers. Figures 12 and 13 provide pictorial comparisons of the existing town site and the proposed town site. Reconfiguring the buildings reduces the area that the town site covers by about 16% while increasing the usable building floor space by about 24%. Table 2 summarizes the functional consolidation of the buildings.

Figure 12. Town site layout for the existing Pegasus airfield (top) and the proposed consolidated airfield (bottom) with the ATCT on the far left (renderings courtesy of CMT Engineering, Springfield, IL).

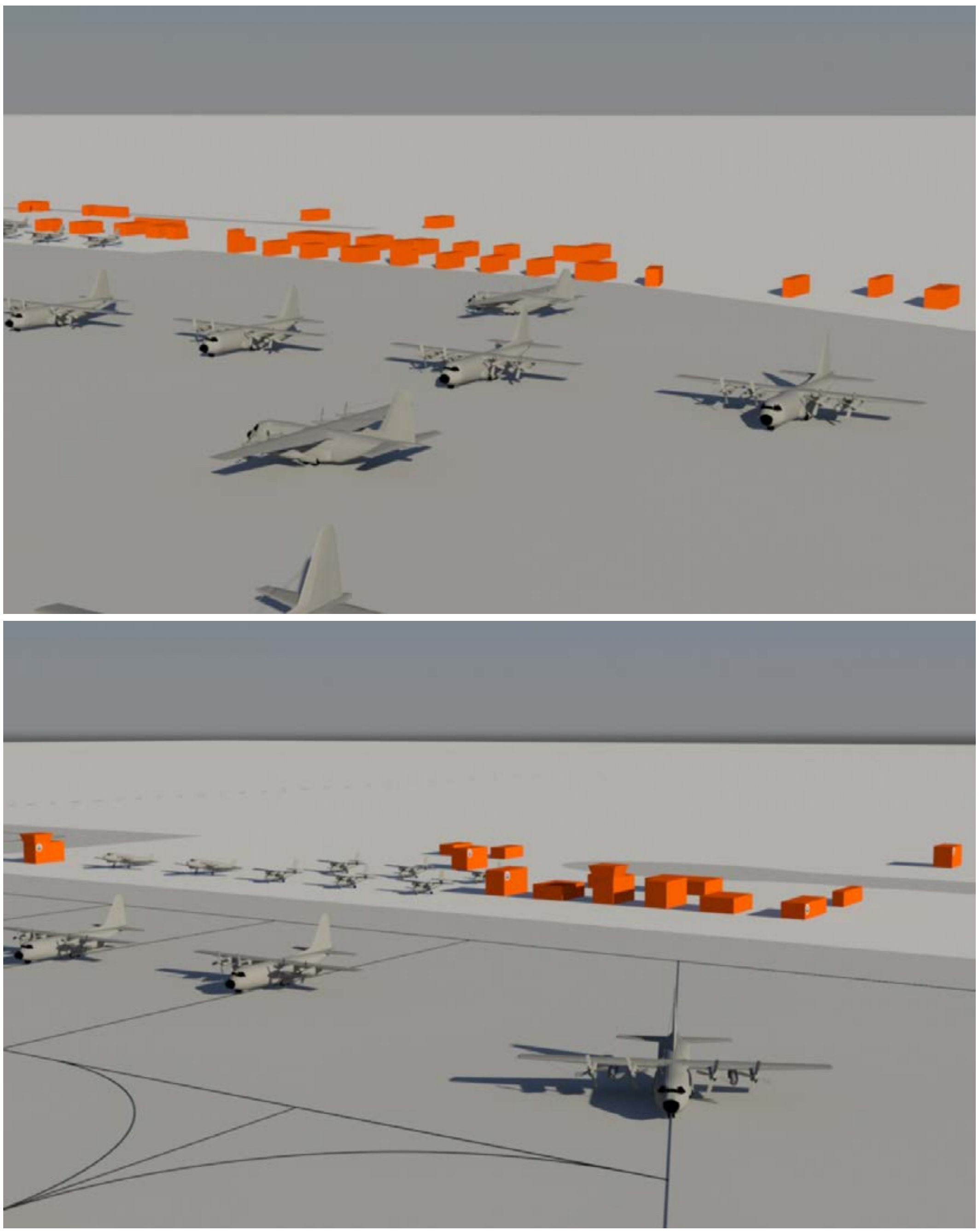
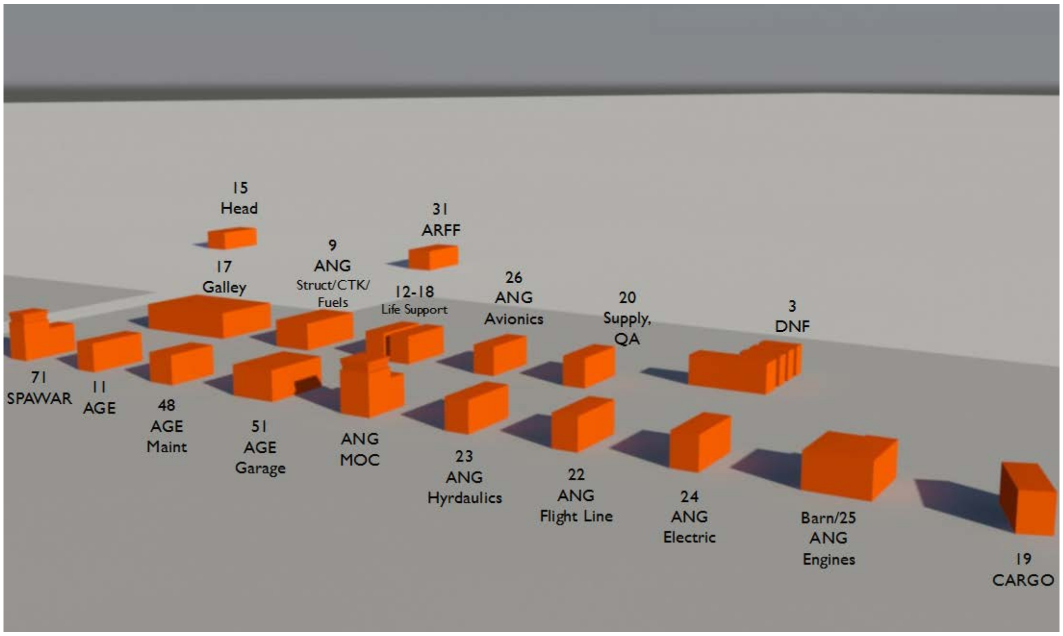


Figure 13. Existing site (top) and proposed layout of the airfield town site with the proposed consolidated buildings (bottom) (Thuma and Gregory 2012). What is not shown in either image are the PAX terminal and Fleet Ops buildings as these are located out of the main town site. Also, the bottom image does not show the ATCT as its proposed location is outside of the main town site.



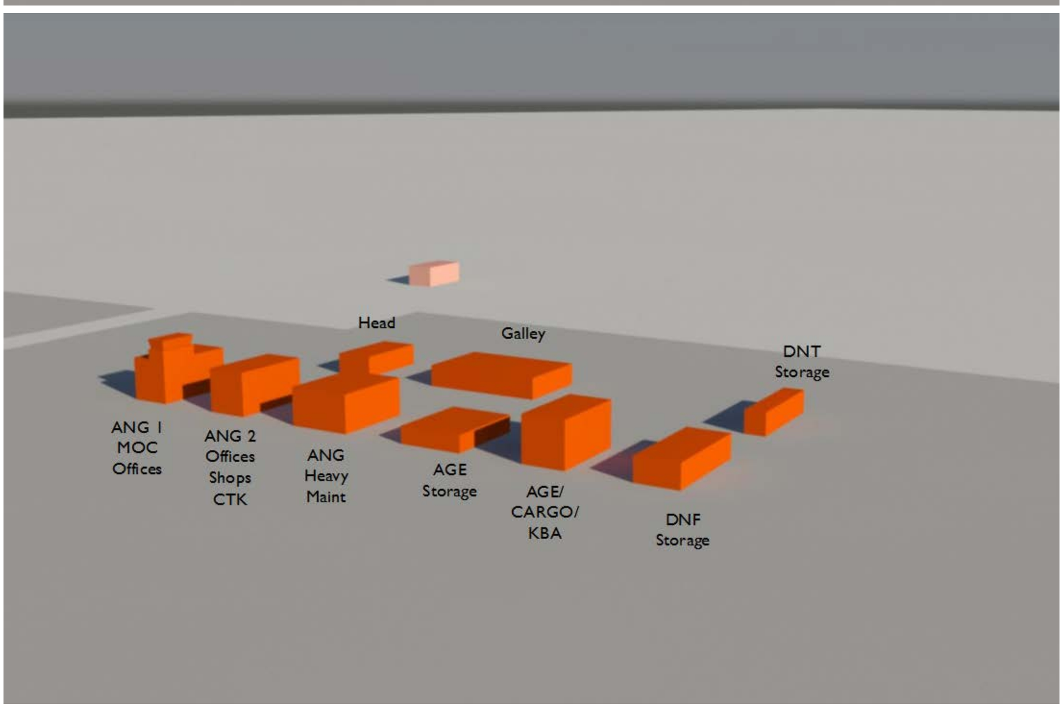


Table 2. Proposed consolidation of buildings by functional area (data from Thuma and Gregory 2013).

Existing Building	Floor Area (sq ft)	Proposed	Floor Area (sq ft)
Air Force/Air National Guard			
ANG structure/CTK/fuels	768	Building 1	2000
ANG life support	768	Building 2	1600
ANG supply and quality assurance	384	Heavy maintenance shop	2400
ANG flight line	384		
ANG hydraulics shop	384		
ANG electric shop	384		
ANG engine shop	384		
ANG avionics shop	384		
ANG engine barn	420		
ANG maintenance operation center (MOC)	624		
Aircraft ground equipment (AGE)/Cargo/KBA			
Do not freeze (DNF) cargo	520	Consolidate office	1600
Cargo	384	DNF Storage	1000
KBA maintenance	384	Do not thaw (DNT) storage	500
KBA maintenance	384	Maintenance shop	1200
KBA maintenance	384		
KBA DNF storage shed	128		
AGE office and telecom equipment	384		
AGE maintenance shop	420		
AGE service garage	840		
SPAWAR			
ATCT	576	ATCT and shop	3900
NAVAIDS shop	576		
Fleet Operations			
Fleet operations tool shed	240	Office	600
Warming hut	630	Vehicle maintenance and tools	2800
PAX Terminal			
PAX terminal	800	PAX terminal and Fitness Center	1600
Galley and Head			
Galley	2700	Galley and kitchen	2400
Head module	800	Head	800
Total	15834		19600

CTK = Consolidated tool kit (tool storage area and metal shop)

The heat loss from a building, or envelope efficiency, is normally estimated based on the ratio of the surface area of the building to the building volume. Everything else being equal, the smaller this ratio, the lower the heating requirements. Thuma and Gregory (2013) use the ratio of surface area of the building to floor surface area as an indicator of the relative energy efficiency of a building and assume the building volume approximately scales with floor space. Using this measure, the consolidated building configuration provides about 25% reduction in envelope area. We expect this will translate to similar savings in heating requirements on this basis alone. Improved insulation, reduction in infiltration, use of passive solar heating, etc., can create further savings.

We note that consolidation of the airfield is consistent with the BRP recommended action 4.4-7 (Augustine et al. 2012) by making ARFF and ATC facilities more sustainable by not stretching those resources over multiple airfields operating simultaneously. Furthermore, consolidation of the runway support facilities as recommended in this section should make them more energy and functionally efficient, thereby better serving the needs of flight operations and reducing the cost of operations. The recommended configuration also eliminates the need for a Sea Ice Runway and retains the Williams Field as an emergency divert site for LC-130s.

4 Remaining Infrastructure Design Issues

The preceding provides a general layout for the consolidated airfield. Final implementation depends on satisfactory resolution of several outstanding issues: timely construction of the snowcap for the wheeled runway, aircraft fuel supply, supply of potable water, handling of waste water, and electrical power supply for the airfield. This section considers each of these.

4.1 Snowcap construction

To reduce the solar radiation energy absorbed by the runway established on glacial ice, ASC annually constructs a thin “white ice pavement,” or snowcap, over the glacial ice runway at Pegasus. This is constructed from available snow, which is distributed over the glacial ice, graded, and compacted to form a strong, reflective surface. The albedo of the snowcap can be as high as 0.7–0.85; by contrast, the albedo of the glacial ice is more typically around 0.5. Thus, the presence of this cap considerably reduces solar radiation absorbed by the runway, delaying or preventing the melting and weakening of the underlying glacial ice pavement that is required to support wheeled flight operations. As per the Pegasus ETL (engineering technical letter) (Department of the Air Force 2002), the maximum allowed thickness of the cap is 5 in.

The normal timetable for constructing the snowcap is to begin collecting snow onto the runway in mid-October. This is followed by grooming and compaction cycles that last about a month. To verify that target runway strengths have been reached, the Air Mobility Command (AMC) typically conducts runway certification* in mid-November in preparation for opening the airfield for operation around 1 December. Also during November, temperature sensors are placed in the runway to monitor the runway surface and subsurface temperatures during the operational season.

To support consolidated airfield operations at or near the current Pegasus airfield, the timing of the construction of the cap needs to be changed to allow opening of the airfield by 1 October, rather than 1 December. One

* The runway needs to be certified that it meets the specifications outlined in Air Force (2002) with respect to markings, lighting, NAVAIDS, length, width, grade, surface strength to support wheeled aircraft, etc.

option would be to start constructing the cap immediately following WINFLY. Unfortunately, the air and ice temperatures during October–November support the rapid sintering required to convert the loose dense snow to a hard white surface that supports wheeled aircraft operations. Starting construction before October may not allow the snow to sinter and strengthen to acceptable levels (see Section 6.2) before the start of MAINBODY flights. Furthermore, weather delays typical of this early part of the season (1 September–1 October) can further compromise the construction schedule.

CRREL and ASC have identified two possible alternatives. One is to do an initial construction of the cap at the end of the operational season, following station close in March. The second is to construct the cap in phases while the runway is in operation. We provide more detailed descriptions of both of these approached below.

We consider wintertime snowcap construction first. By placing the snow and conducting initial compaction and grooming cycles in early winter, the cap may have sufficient time to sinter over the winter. Final cap compaction and grooming can then occur immediately following WINFLY with certification occurring in late September prior to MAINBODY start. Also, the temperature sensors would need to be installed in the runway during September. The analysis of wintertime temperatures and sintering provided in Appendix E suggests that wintertime construction of the snowcap could provide a cap strength as much as 4 times stronger than is achieved by the existing construction timetable (i.e., starting cap construction in October). Though the sintering process proceeds more slowly in the winter, the increased time allowed for the sintering may lead to much higher strengths. Like conventional snowcap construction (e.g., carried out in October–November), the success of wintertime cap constructions depends on the availability of fine-grained snow.

We note however, that because the sintering progresses more slowly, the snowcap strength will initially be weaker than what is achieved during normal cap construction time frames (i.e., at the conclusion of winter cap construction [about 15 April] the estimated strength will be about half that of a completed cap constructed during October–November). Yet, by the end of May, the cap constructed during the winter is projected to have strength about the same as a cap constructed following current practice (see Appendix E). Therefore, there may be about a 2–3 month period (1

March–31 May) where mid-winter MEDEVACs need to be accomplished with ski-equipped aircraft until adequate cap strength is achieved.

To explore the viability of this option, we recommend that a test section be constructed in the overrun area on the south end of the Pegasus white ice runway during the winter of 2015 following station close. This should receive more attention the following WINFLY to prepare it as a flight surface, and the runway strength in this section should be evaluated periodically through the winter and prior to the start of MAINBODY to understand how the strength can be expected to improve through the construction and winter periods. It should also be evaluated throughout the season to ensure that the performance of this surface is comparable to the cap constructed by conventional methods and on the standard timetable. In addition to regular strength evaluation using the Russian Snow Penetrometer (RSP), flight crews should be instructed to make turns with the aircraft (e.g., C-17) in this test section to demonstrate that the strength is sufficient to support normal operations. This evaluation could also provide some insights to constructing a surface that supports wheeled aircraft on a compacted snow foundation (i.e., no near-surface glacial ice).

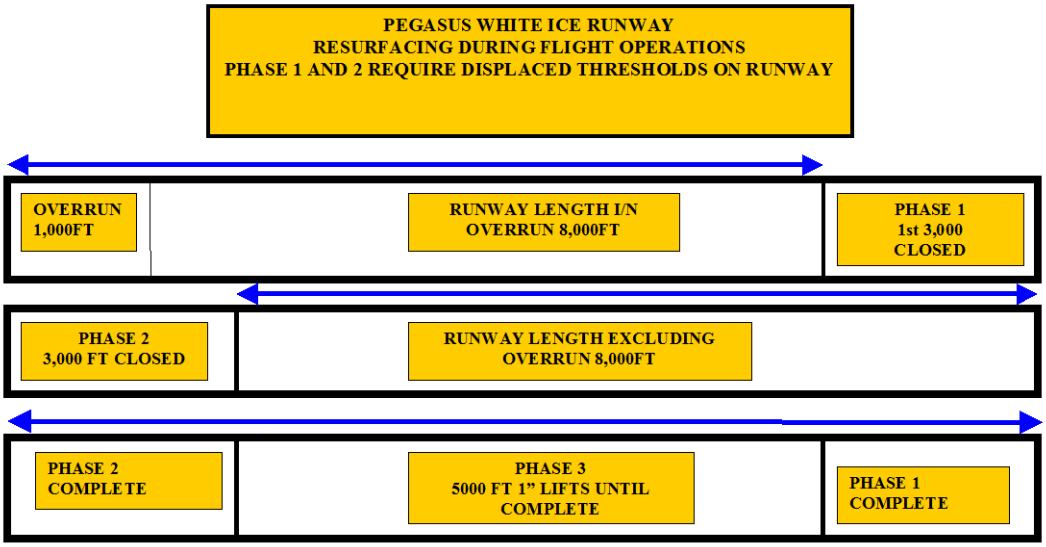
If this method proves unsatisfactory, an alternate means of constructing the snowcap on the glacial ice may be suitable. Progressive capping of the runway was carried out during October–November 2012. This was necessitated by the need to operate wheeled aircraft intermittently out of Pegasus during the early part of MAINBODY because of thinner than normal sea ice in the McMurdo Sound, limiting the load carrying capacity of the ice on which the Sea Ice Runway was constructed.

During this time, the capping was done in phases, as depicted in Figure 14.

In Phase 1, the first 3000 ft (north end) of the runway was closed for cap construction. The remaining 7000 ft plus the 1000 ft overrun—total of 8000 ft—was used for flight operations as indicated by the blue line in Figure 14. Once Phase 1 was complete, the last 2000 ft plus the overrun was closed for cap construction (Phase 2); the north 8000 ft of the runway was used for flight operations. Sections between the new caps and the existing runway were planed to provide a smooth transition between the new cap and the runway. During Phases 1 and 2, the runway thresholds on the north and south needed to be displaced from their normal position; the north threshold was displaced 3000 ft during Phase 1 and the south

threshold was displaced 2000 ft during Phase 2. Working in phases such as this requires a waiver from the AMC to reduce the operational runway length and to operate with a displaced threshold.

Figure 14. Illustration of the sequencing of capping the Pegasus white ice runway during the start of MAINBODY 2012.



During Phase 3, the remaining 5000 ft of runway was capped in 1 in. lifts until it was complete. Because the white ice runway typically services only 2–3 flights per week, the cap construction during Phase 3 takes place during the time between scheduled flights.

When the snowcap is constructed in phases as described above, the strength of each newly constructed cap needs to be verified before it is brought into service. The estimated time it takes to complete cap construction following this method is 7 weeks with Phases 1 and 2 taking 2 weeks each.

We note that if the consolidated airfield were constructed at the alternate location (e.g., near milepost 10) as discussed in Section 2, construction of a snowcap may not be necessary. However, the need to construct a snowcap may be replaced with the need to construct and compact a snow pavement layer over the existing compacted runway surface. Yet, the timing and effort for such an operation may be similar to snowcap construction. As such, similar runway construction strategies to what we propose in this section for snowcap construction may be needed if the final location of the consolidated airfield is near milepost 10. Further development of construc-

tion and maintenance procedures of a wheeled runway in deep snow is needed to be able to determine the required schedule to provide a runway at this alternate location.

4.2 Aircraft fuel supply

To maintain flight operations, a supply of aviation fuel (AN8) needs to be maintained at the airfield from WINFLY through season close. To accommodate the beginning of the season, including WINFLY, about 120,000 gal.* of fuel is left in tanks at the airfield at the end of the season† (102,000 gal. in the 12 tanks for the skiway and approx. 16,000 gal. in the tank for aircraft using the runway). This provides the 42,000 gal. needed to support WINFLY and 16,000 gal. for contingency (e.g., winter MEDEVAC), leaving a total of about 60,000 gal. for initial operation of MAINBODY flights at Pegasus, which historically starts about 1 December.

Since the 2009–10 season, the fuel needed at Pegasus has been supplied via a flexible hose that is deployed every season before the start of Pegasus MAINBODY flight operations and removed after conclusion of the LC-130 operations at Pegasus (shortly after South Pole station closes on about 15 February). For the remainder of the season, the fuel needed at Pegasus comes from fuel stored on site or, at the end of the operational season, from pushing the fuel out of, or pigging, the fuel lines between the auxiliary pump station and Pegasus.

To support a consolidated airfield, fuel operations need to be modified to support C-17 flights arriving at Pegasus on a scheduled opening for MAINBODY that is typically around 1 October and for the start of LC-130 operations around 26 October. To support this, we recommended that the amount of fuel stored at Pegasus at station close be sufficient to accommodate the flight ops at Pegasus airfield 1 October–1 November in addition to the 58,000 gal. required for WINFLY and contingency. As stated above, at station close 2011–12, there was an additional 42,000 gal. of fuel stored at Pegasus. Table 3 tabulates the recent history of fuel used during the early MAINBODY period (roughly October–1 November). From this, it is clear that the amount used can vary widely depending on the operational tempo required for C-17 flights in the early part of MAINBODY, which

* U.S. Gallon

† Emily Hart, Lockheed Martin. Personal communication, 18 May 2012.

can vary from season to season. Yet, the historical demand is less than the 60,000 extra gallons presently stored at Pegasus. Therefore this demand can reasonably be met with available or slightly augmented storage capacity at Pegasus.

Table 3. Summary of aviation fuel use during the early MAINBODY period spanning from the opening of MAINBODY operations at the Sea Ice Runway until the start of the LC-130 operations (approximately October–1 November annually).

Season	Aviation Fuel Used (gal.)
2009–10	32,808
2010–11	24,897
2011–12	5681

Yet, establishing a consolidated airfield advances the timetable for providing 175,000–250,000 gal. of fuel to Pegasus to support LC-130 operations by about 1 month (from approximately 1 December to approximately 1 November). This means the pipeline to support these regular fuel transfers needs to be in place a little over a month earlier than currently required.

Advancing placement of the hose by one month or more means that the fuel crew would be working in more adverse weather. This will likely increase the time to deploy the hose from the current time of 6 people working six weeks and may include more weather delays that will prevent the personnel from working.

In addition to deployment, we need to consider pickup of the hose. Presently, pickup of the hose starts at the end of the LC-130 operations, which is about 15 February annually, and lasts through early March. Previously, McMurdo Station closed about 21 February when the last flight leaves the continent. However, in recent years, to allow time to pick up the fuel hose, the last flight has been pushed out approximately 2 more weeks (early March).

A possible solution that would eliminate the need for earlier hose deployment and a March pickup is installing heavier hose that can be left in the field year round. From experience at Marble Point, a reasonable life expec-

tancy of the heavier hose is at least 10 years*. Though using this hose would eliminate the need to deploy and pick up the hose, the hose will still need to be strapped to the surface† periodically throughout the winter months to prevent the line from being buried under accumulating snow.

Clearly, issues related to providing a fuel supply at the airfield and fitting that into the overall season schedule need further refining before phasing over to operating a consolidated airfield through the entire MAINBODY season.

4.3 Potable water supply

The increased crew to support operating LC-130s at Pegasus necessitates providing similar galley services to what was formerly provided at Williams Field. Though at present, food preparation is not provided at Pegasus, adding that capability will improve the quality of the food available at the airfield and will reduce the frequency of transporting food between McMurdo and the airfield. Serving the increased crew at the airfield and eventually preparing food on-site requires a long-term method to provide potable water at Pegasus. Currently, potable water is trucked from McMurdo to Pegasus; non-potable water needed for flushing toilets, etc., is provided via an on-site snow melter.

During the 2011–12 season, Pegasus used about 7900 gal. of potable water. The usage increased to 12,900 gal. in 2012–13‡. That equates to transporting over 1000 gal. per week from McMurdo to Pegasus. This puts an additional strain on the snow roads, and cargo-hauling equipment needs to be diverted to handle water transport. When on-site food preparation is implemented, the potable water need is estimated to grow to at least 3000 gal. per week§.

Possible methods that have been identified in addition to trucking water include (1) melting and treating snow or ice on-site and (2) a small-scale

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* Alex Morris, Fuels Supervisor, Antarctic Support Contract, Centennial, CO. Personal communication, 22 March 2012.

† A strap is slung under the hose and used to pull the hose to the top of the snow surface.

‡ Anthony Andrade, Utilities Manager, Antarctic Support Contract, Centennial, CO. Personal communication, 31 May 2013.

§ Estimate determined at the Single Airfield Complex Review meeting, 21–22 April 2011, Centennial, CO.

reverse osmosis plant for converting salt water to fresh water, such as what is used in McMurdo to produce potable water.

To meet this demand, we recommend conducting a review of available methods and developing a suitable solution from that.

4.4 Waste water handling

At the onset of LC-130 operations at the Pegasus airfield in 2009–10, it became clear that handling wastewater would become a major issue. Prior to this point, minimal waste was generated at Pegasus airfield as only 2–3 flights per week were scheduled to land. This small quantity of black water was handled by disposing of the waste in 55 gal. drums and shipping it back to the U.S. for treatment (Melendy et al., 2014). Following consolidating operations of the C-17s and LC-130s at Pegasus, from 2009–10 to the 2011–12 seasons, the amount of wastewater (gray and black water) produced at the airfield has been on average approximately 23,000 gal. over the 10 week operational period (Melendy et al., 2014). However, during the 2012–13 season, the wastewater generated at Pegasus was 36,370 gal.*—a dramatic increase over prior years.

Melendy et al. (2014) explored several alternatives to barreling waste and evaluated two proof of concepts—treating the waste at the waste water treatment plant (WWTP) in McMurdo and on-site incineration—at Pegasus during the three summer seasons spanning 2010–2013. Both concepts proved successful in achieving their stated objectives of handling the planned waste stream. However, they identified several issues that need attention before either of these methods are implemented as a long-term solution for the proposed consolidated airfield. The next section provides a summary of the implemented methods and issues identified.

4.4.1 Treatment at McMurdo waste water treatment plant

To treat the wastewater using the WWTP in McMurdo, the waste needs to be transported 16.5 miles—14.5 miles on snow roads—back to the plant in McMurdo. To facilitate this, a 1000 gal. vacuum tank was purchased and installed on the bed of a cargo truck. Initial issues related to design of the

* Anthony Andrade, Utilities Manager, Antarctic Support Contract, Centennial, CO. Personal communication, 31 May 2013.

winterization of the vac tank were readily overcome. However, the main issues that need addressing are as follows:

1. Rapid dumping of large quantities of waste into the WWTP shocks the system. To prevent this, an equalization tank needs to be installed at the WWTP. The waste can then be dumped into the holding tank and metered into the WWTP over a 12–24 hour period.
2. The current vac tank and transport system have insufficient capacity. If this is the sole means of waste handling, a second vac tank of similar capacity should be purchased (for redundancy), and a dedicated prime mover needs to be made available to keep up with the waste stream. The prime mover also needs to be able to traverse the snow roads during the warmest time of year when the roads are weak; therefore, it needs to be a low ground-pressure vehicle.

A major long-term drawback of this method is reliance on the snow road system for transport. Like trucking potable water discussed previously, addition of waste transport to the load on the roads will further strain a snow road system that already is heavily used by crew and passenger shuttles and cargo transport.

4.4.2 On-site incineration

Incineration of the wastewater was handled by a system that had 4 independent onboard burners. Though the incinerator could have handled both grey and black water, for the proof of concept it was set up so the effluent from the head module was transferred directly to the onboard storage tank. Waste was then automatically pumped from the storage tank to each burner and incinerated. The system could be set to automatic mode wherein waste was metered out to each burner from the storage tank until the tank was empty, at which point the burners were put in standby mode. The main drawback with the incinerator system was the odor of the flue gas emitted from the burner. It was considered so bad that it made some people who worked throughout the airfield complex nauseated and unable to work effectively. To prevent this problem during the proof of concept, operation of the incinerator was limited to times when the bulk of the personnel were not at Pegasus; this limited how much waste could be processed. For this technology to be adapted for use at Pegasus, additional work needs to determine the source of the odor and to develop means to eliminate it, either by using alternative incineration technologies (e.g.,

higher temperature incineration) or by refining the system used in the proof of concept.

4.4.3 Other methods

Through an initial evaluation of available waste-handling methods, the ones tested in the proof-of-concept evaluation described above were considered the easiest to adapt to the Pegasus airfield with minimal re-engineering and produced minimal environmental impact. Several other methods were identified at that time that may be viable. These include the following:

1. On-site waste water treatment
2. Disposal of waste into the glacial ice
3. Disposal of waste into the McMurdo Sound through the Ross Ice Shelf (if located at Pegasus site)
4. Disposal into snow like what was done for many years at Williams Field (if located at milepost 10)

In addition to further development of the methods tried in the proof-of-concept tests, these and other methods should be further explored to determine the best long-term solution for waste handling at the consolidated airfield.

4.5 Airfield electric power plant

Current operations at the Sea Ice Runway and at Pegasus require several generators to support all of the needed functions. The Sea Ice Runway uses three generators and Pegasus uses five generators of varying sizes (the main generator and several other smaller generators used to get power to more remote buildings and facilities). Yet, in the case of Pegasus, much of the power generation can be accomplished using a single generator, provided thought is given to the long-term location of buildings and routing of connecting feed cables. Therefore, in addition to upgrading and consolidating the runway support facilities (Section 3.3), proper sizing and replacement of the aging* power generation equipment needs to be addressed. The anticipated timing to determine the required size of the

* The current main generator set (building 471) was purchased in 1993 and is therefore about 20 years old.

generator and feed line layout would be near the completion of the design of the runway support facilities as proper sizing of the generator cannot be finalized until the power requirements for all of the support facilities is determined. Therefore, we expect that the new generator would be commissioned at about the same time that the last of the runway support facilities are delivered.

5 Timeline for Consolidated Airfield Implementation

Owing to design, acquisition, transportation, and construction, the timeline for complete implementation of the proposed consolidated airfield will take approximately 7 years. Appendix F provides a draft timeline for implementation, and we provide a summary here.

Table 4 gives the sequencing of the major components that need addressing. This schedule assumes starting all aspects of the airfield implementation as early as is possible within the confines of being able to work on certain phases only during the Antarctic summer; and transport of materials and equipment by vessel requires about a 1 year lead time from the date it reaches shipping ports in the U.S. to being available for use in the Antarctic summertime*. By starting every task early in the cycle, buildings and resources can be used as soon as they are available, allowing realization of planned benefits and efficiencies as early in the cycle as possible. For example, low environmental impact waste-handling facilities can be commissioned and used at existing airfield facilities as soon as they are made available and then can be transferred over to the final consolidated airfield once it is completed. Furthermore, because not all phases are completed simultaneously, there will be phased commissioning of components, avoiding troubleshooting of all of the components at the same time.

Appendix F provides the more detailed view showing, for example, that design and construction of the runway support facilities are planned to occur in three phases with the highest priority facilities (ATCT and NYANG support buildings) being commissioned by the end of the third year and lower priority facilities being delivered in years 4 and 5.

The disadvantage of the approach laid out in Table 4 is that a large portion of the funding needs to be committed upfront rather than phased in over several funding cycles.

* Equipment and supplies shipped by vessel leave the U.S. in November and arrive in McMurdo just before station close (February). Therefore, often these resources cannot be used until the following September (spring).

Table 4. Summary of the schedule for consolidated airfield implementation. Phasing timeline assumes a 1 May start for the entire project. The start time of individual tasks may shift depending on actual start date.

Task	Start (years into phasing)	Duration (years)	Expected Completion (years into phasing)
Fuel delivery system	0	2.4	2.4
Runway support facilities	0	5	5
Potable water supply	0	2.8	2.8
Waste-water handling	0	2.8	2.8
Airfield power supply	2.8	2.6	5.4
Winter cap construction testing	0.8	1.2	2
Access roads equipment and guidance*	0.5	5.4	5.9
Replacement shuttles*	0.5	5.4	5.9
Airfield construction and commissioning	0.5	6.3	6.8

* Though the roads and shuttles are an important part of the implementation of a consolidated airfield, the details of this aspect are treated separately under the NSF-PLR project "Snow Roads and Transportation."

6 Operations

Here we provide an overview of planned consolidated airfield operations. This is a draft schedule that adapts current tasks required for airfield operations at the 2 to 3 airfields to a timeline required for a single airfield.

6.1 Season timeline

6.1.1 WINFLY

The initial opening of flight operations begins with WINFLY providing the crew and supplies needed to facilitate station opening. This occurs soon after sunrise in late August and historically comprises 4–5 flights of wheeled C-17 aircraft. The consolidated airfield needs to support this operation with minimal preparation from the winter-over crew. The preparation entails clearing the runway of accumulated snow and drifts so the hard runway surface from the previous season is exposed and setting up support facilities for flight, such as ATCT, NAVAIDS and runway markers, firefighting equipment, etc. Also, as part of this effort, the access road needs to be cleared and adequately compacted to support transport of cargo and passengers arriving or departing at WINFLY.

Preparations for WINFLY usually start about 7 weeks before the arrival of the first flight and are carried out by the winter crew. For consolidated airfield operations, we do not expect that the schedule or preparations for WINFLY will vary much from the current practice. Table 5 provides a summary of the schedule surrounding WINFLY. This table assumes WINFLY starts on 21 August; typically this varies by a day or two from year to year, and the schedule will need to be adjusted accordingly. Along with the approximate dates of each task, the number of days leading up to (-) or following (+) the start of WINFLY is indicated in parentheses by the date.

Table 5. General schedule for preparations for WINFLY. Approximate start date of 21 August (indicated as day 0). Adapted from a draft schedule to support flight operations out of only Pegasus Airfield during the 2012–13 season*.

Start	End	Task	Responsible Party
Mar	Aug	Maintain the Scott Base transition and snow roads over the winter	Fleet Ops
1 Jul (−52)	20 Aug (−1)	Groom and prepare runway for WINFLY	OPS/HEO
5 Aug (−16)	20 Aug (−1)	Prepare ARFF resources (trucks, etc.)	Fire Department
6 Aug (−15)	8 Aug (−13)	Power up TACAN for WINFLY	FE/Linemen
12 Aug (−9)	15 Aug (−6)	Set up fuel pump and tank for WINFLY	Fuels
12 Aug (−9)	15 Aug (−6)	Install runway markers and windsock	HEO
12 Aug (−9)	15 Aug (−6)	Install main generator	OPS/HEO
12 Aug (−9)	15 Aug (−6)	Install REIL/PAPI lights	SPAWAR
12 Aug (−9)	15 Aug (−6)	Power up MLS and PAPI	AGE/OPS
12 Aug (−9)	15 Aug (−6)	Install DNF storage, PAX terminal, ATO (cargo), KBA office, fire station, fleet ops, control tower and head module buildings	OPS/HEO/All Trades
15 Aug (−6)	15 Aug (−6)	Power up SSALR	FE
15 Aug (−6)	18 Aug (−3)	Hook up telecom and network at fleet ops and the control tower	IT
15 Aug (−6)	18 Aug (−3)	Inspect runway	NSF/OPS Supervisor
18 Aug (−3)	18 Aug (−3)	Open runway	Winter Ops Supervisor
20 Aug (−1)	5 Sep (+14)	Have ATCT operational	SPAWAR
20 Aug (−1)	1 Oct (+40)	Maintain runway	HEO
21 Aug (0)	29 Aug (+8)	Begin WINFLY at consolidated airfield (starts approx. 21 Aug annually)	Airfield Manager

* Gary Cardullo, Airfield Manager, Antarctic support Contractor, Centennial, CO. Personnel communication, 23 May 2012

ATO = Airfield transport office

FE = Facilities engineer

HEO = Heavy equipment operator

IT = Information technology

OPS = Office of Public Safety

PAPI = Precision approach path indicator

REIL = Runway end identifier lights

SSALR = Simplified short approach lighting system with runway alignment indicator lights

6.1.2 MAINBODY

Following WINFLY, the airfield needs to be prepared for MAINBODY flights with C-17 flights starting approximately 1 October and LC-130 flights starting approximately 26 October when the skiway at South Pole opens. The following need to be completed to support MAINBODY:

1. Construct and maintain the access road
2. Deploy fuel delivery system
3. Set up town site
4. Construct skiway

Much of the runway markers, NAVAIDS, and the control tower remains in place from WINFLY, so those do not need to be addressed for MAINBODY.

Table 6 provides a draft schedule for the MAINBODY season. This schedule assumes that wintertime construction of the snowcap is a viable method; therefore, construction of the snowcap is not required during preparations for MAINBODY or during MAINBODY. If we discover that wintertime cap construction is not viable, then we will need to modify the schedule to allow for cap construction during air operations in October and November as described in Section 4.1.

Table 6. General schedule for MAINBODY preparations and operations. Approximate start of MAINBODY is 1 October (indicated as day 0). Adapted from draft schedule to support flight operations out of only Pegasus Airfield during the 2012–13 season*.

Start	End	Task	Responsible Party
8 Aug (−55)	28 Sep (−3)	Keep TACAN/PAPI/REIL powered up	SPAWAR/FE
20 Aug (−43)	1 Oct (0)	Maintain runway	HEO
Aug	1 Oct (0)	Compact access roads	HEO
26 Aug (−36)	19 Oct (−12)	Deploy fuel hose	Fuels
1 Sep (−31)	19 Oct (−12)	Construct consolidated airfield skiway, taxiway, and ramp	HEO
15 Sep (−16)	18 Sep (−13)	Set up remaining town site, including electrical grid	HEO/Linemen/FE
15 Sep (−16)	17 Sep (−14)	Install runway temperature sensors (2 weeks prior to MAINBODY)	Surveyors
17 Sep (−14)	17 Sep (−14)	Ensure control tower and TACAN are operational	FE/SPAWAR
20 Sep (−11)	22 Sep (−9)	Start monitoring runway temperatures	IT/Airfield Manager
24 Sep (−7)	25 Sep (−6)	Power up MLS/SSALR	FE/AGE/SPAWAR
28 Sep (−3)	28 Sep (−3)	Install runway markers, windsock, and weather visibility board	Surveyors
1 Oct (0)	5 Mar (+150)	Begin MAINBODY at consolidated airfield	Airfield Manager
1 Oct (0)	5 Mar (+150)	Maintain access roads	HEO
8 Oct (+7)	8 Oct (+7)	Power up TACAN at Williams Field	FE/Linemen
15 Oct (+14)	20 Oct (+19)	Expect the first KBA aircraft to arrive	Airfield Manager
15 Oct (+14)	20 Oct (+19)	Groom both Williams Field skiways in preparation for LC-130 arrival (1 week prior to their arrival)	HEO
19 Oct (+18)	19 Oct (+18)	Install skiway markers (72 hr prior to LC-130 arrival)	Surveyors
20 Oct (+19)	20 Oct (+19)	Make first fuel transfer to consolidated airfield	Fuels
20 Oct (+19)	21 Oct (+20)	Survey air and ground WO landing area	Surveyors
21 Oct (+20)	20 Feb (+142)	Open Williams Field for LC-130 divert	Airfield Manager
21 Oct (+20)	20 Feb (+142)	Open WO landing area	Airfield Manger
22 Oct (+21)	20 Feb (+142)	Open consolidated airfield skiway	Airfield Manger
22 Oct (+21)	22 Oct (+21)	Expect first LC-130 to arrive	Airfield Manger
26 Oct (+25)	15 Feb (+137)	Open South Pole skiway	Airfield Manger
12 Nov (+42)	23 Nov (+53)	Receive annual AMC certification for McMurdo Runway	Airfield Manger
18 Feb (+140)	20 Feb (+142)	Expect LC-130s to depart for the season	Airfield Manger
23 Feb (+145)	23 Feb (+145)	Expect last C-17 to leave McMurdo	Airfield Manger
6 Mar (+156)	8 Mar (+158)	Close consolidated airfield once last flight reaches Christchurch, NZ	Winter Ops Supervisor

* Gary Cardullo, Airfield Manager, Antarctic support Contractor, Centennial, CO. Personnel communication, 23 May 2012.

6.1.3 Close out

In late February, LC-130 operations end after South Pole closes on about 15 February. Following this, removal of the fuel lines starts; and the summertime population begins to leave. The last flight out is around 5 March,

following retrieval of the fuel lines. This marks the close of McMurdo Station for the winter. Table 7 provides a summary of the close out schedule. Note that this schedule includes in March and April the wintertime construction of the snowcap on the runway in preparation for the following season.

Table 7. Schedule for close out of the airfield in preparation for winter. End of the season starts 5 March (indicated as day 0). Adapted from a draft schedule to support flight operations out of only Pegasus Airfield during the 2012–13 season*.

Start	End	Task	Responsible party
10 Feb (–22)	10 Feb (–22)	Remove runway temperature loggers and shutdown runway monitoring system	Surveyors
18 Feb (–15)	20 Feb (–13)	Expect LC-130s to depart for the season	Airfield Manger
19 Feb (–14)	20 Feb (–13)	Close down Williams Field after last LC-130 reaches Christchurch, NZ	Airfield Manager
19 Feb (–14)	20 Feb (–13)	Power down Williams Field TACAN and AWS and place in winter storage	SPAWAR/VMF/HEO
19 Feb (–14)	19 Feb (–14)	Remove Williams Field skiway markers	Surveyors
19 Feb (–14)	19 Feb (–14)	Shut down power to ANG buildings and move them to winter storage	All trades
21 Feb (–12)	4 Mar (–1)	Remove fuel line	Fuels
23 Feb (–10)	23 Feb (–10)	Expect last C-17 to leave McMurdo	Airfield Manger
5 Mar (0)	5 Mar (0)	Expect last flight to leave McMurdo	Winter Ops Supervisor
6 Mar (+1)	8 Mar (+3)	Close consolidated airfield once last flight reaches Christchurch, NZ	Winter Ops Supervisor
7 Mar (+2)	8 Mar (+3)	Power down remaining buildings in town site and move them to winter storage	All trades
7 Mar (+2)	8 Mar (+3)	Transfer remaining AGE back to McMurdo Station for storage	AGE/HEO
7 Mar (+2)	8 Mar (+3)	Remove runway markers and windsocks from runway	HEO
7 Mar (+2)	8 Mar (+3)	Remove any snow drifts from town site	HEO
7 Mar (+2)	8 Mar (+3)	Power down generator and move them to winter storage	All trades
7 Mar (+2)	8 Mar (+3)	Power down AWS and REIL and move them to winter storage	SPAWAR
7 Mar (+2)	8 Mar (+3)	Power down PAPI, TACAN, and SSALR and leave them in place for WINFLY	SPAWAR
10 Mar (+5)	15 Apr (+36)	Construct new snowcap on runway	Fleet Ops/Survey

* Gary Cardullo, Airfield Manager, Antarctic support Contractor, Centennial, CO. Personnel communication, 23 May 2012.

AWS = Automatic weather station

VMF = Vehicle maintenance facility

6.2 Managing warm weather during MAINBODY

As discussed in Section 4.1, because the runway and skiway are founded on ice and snow, the performance of these surfaces can degrade significantly in warm weather. One critical factor for minimizing strength degradation of these surfaces is keeping the albedo as high as is practical; this reduces heating from solar radiation. This is done by trying to avoid getting dirt and soot on the surfaces and by freshening up the surfaces with new snow when possible.

Generally, the skiway is less sensitive than the runway. Because the LC-130s can land on skis, they tolerate a much lower surface strength. However, a very wet, soft surface increases the drag and makes it very difficult for take-off with a full load. Therefore the maximum allowable load may need to be reduced during severe melting of the skiway.

Also discussed in Section 4.1, the runway is annually capped with a compacted snow surface to reduce absorption of solar radiation. The strength of the snowcap needs to be preserved to support wheeled flight. To evaluate the strength, an RSP is used (Department of the Air Force 2002). As stipulated by the Department of the Air Force (2002), AMC runway certification requires that the strength be measured at 126 locations along the length and width of the runway. From these measurements, the following strength statistics are computed:

1. Mean RSP Index—average of all individual penetrometer test site values. This mean value must match or be higher than the minimum values determined for the aircraft tire pressure.
2. Lower RSP Strength Limit—85% of all of the individual penetrometer test-site values must match or exceed this lower limit.

Table 8 gives the minimum Mean RSP Index and Lower RSP Strength Limit required for safe landing and take-off on the runway as a function of tire pressure.

Table 8. Minimum mean RSP index required on the runway for safe flight operations (from Department of the Air Force 2002 except where noted).

Aircraft	Tire Pressure (psi)	Mean RSP Index	Lower RSP Strength Limit
C-130	95	55	45
C-17	155	60	46
Airbus A319	210	70*	50*

* Determined based on extrapolation of data in Figure 9 and Table 5 of Department of the Air Force (2002) for use starting in 2012–13 season (George Blaisdell and Gary Cardullo, personal communication, December 2012).

As the ice temperature approaches the freezing point (32°F), maintaining the RSP above the minimum index becomes difficult to do even when the surface albedo remains high. This is especially true when the sun is high in the sky (noon or early afternoon). We note that there is a strong diurnal cycle in the strength with the runway strength reaching a minimum at around 1400–1600 local time, and the strength recovers to a maximum at around 0300–0600 local time. To manage the runway strength during the warmest part of the year (approximately 15 December–20 January), the support contractor implemented a warm weather standard operating procedure (SOP) starting in 2011–12; and it has been in use since then. We recommend that this SOP should be carried forward as a way to manage warm weather at the consolidated airfield. This SOP is included as Chapter 11 in the *Airfield Operations & Management* manual (ASC 2012) for McMurdo. A summary of this SOP is provided next.

As part of the SOP, temperature sensors are installed in the runway at 4 locations: at the centerline at both the 3000 and 7000 ft markers along the runway and also 50 ft offset from the centerline at both locations. The temperature is measured at 7 depths in the runway at each location, starting at 4 in. below the surface and progressing in 2 in. increments to 16 in. The temperature profile obtained with these sensors is used to extrapolate the runway surface temperature, which is used to support operational decisions during warm weather.

The SOP dictates monitoring both the runway surface temperature and strength; and once the maximum daily surface temperature reaches 30.2°F, the runway is restricted to night time operations only. Therefore, the wheeled flights land when the runway is at its maximum daily strength, at around 0400 local time.

To measure the RSP Index at all 126 locations specified for runway certification typically requires 2–3 days. This is not practical for a periodic assessment of the runway strength. Therefore, periodic strength assessment is accomplished by taking measurements at 13 locations along the length and width of the runway and determining the Mean RSP Index from this data. If the measured mean drops below the minimum values indicated in Table 8, the support contractor takes corrective measures to restore runway strength before flight operations resume. To ensure that the strength is above the specified RSP value for the aircraft, this strength measurement is carried out 24 hr before the planned flight arrival time.

This SOP was used without incident for the two seasons, spanning 2011–2013.

7 Conclusions and Recommendations

We provide a conceptual design for a consolidated airfield at McMurdo, Antarctica. This design includes a skiway to support ski-equipped aircraft (e.g., LC-130) and a runway for wheeled aircraft (e.g., C-17). Additionally, we review the considerations for siting the consolidated airfield. Based on this study, we identify two possible locations:

1. In the vicinity of Pegasus airfield. The runway would be relocated about 2000 ft east of the current runway to account for ice shelf movement causing the runway to drift from its original geographic location.
2. Near milepost 10 on the current access road to Pegasus airfield. This would locate the airfield outside of the main influence of the dust plume from Black Island.

Final determination of the airfield location depends on whether the snow accumulation and lack of glacial ice at milepost 10 make it too difficult to establish a runway that can support wheeled aircraft and on the ability to create a suitable airspace design (TERPS).

Thuma and Gregory (2013) determined the optimal configuration of the runway, skiway, taxiways, aprons, etc., through an AMP study. A summary of that study is provided in our report. Most notably, Thuma and Gregory (2013) recommended the orientation of the skiway is grid heading 70°–250°. The orientation of the runway depends on the final location of the airfield. If located at Pegasus, we recommend a grid heading 150°–330° (approximately aligned with the net zero ablation line of the ice shelf); if located near milepost 10, the orientation can follow recommendations of the AMP: grid heading 170°–350°. The only limitation on these headings is possible modification to satisfy acceptable TERPS.

Williams Field will continue to be maintained as an emergency divert site for LC-130s. We recommend that the WO landing area remain in its current location east of Williams Field as any modification will provide only an incremental reduction in recovery distance to the consolidated airfield; and because a TACAN is already required for Williams Field, this would continue to be used for guidance of aircraft to the WO landing area.

The AMP shows that consolidating building functionality can reduce the number of runway support buildings from 27 to 14, reducing the plan area of the town site by about 16% while increasing the usable floor space by about 24%. Consolidating buildings and reducing the size of the town site reduces the travel distance between buildings and across the airfield, improving the efficiency of operations. Also, energy efficiency of the buildings should improve from the reduction of the surface-area-to-volume ratio of the buildings affected by consolidation.

In the proposed design, the overall area of the airfield is reduced by about 8%, reducing the area that needs to be regularly maintained and groomed.

Remaining issues to address before implementing a consolidated airfield follow:

1. Revising procedures for annual construction of the snowcap on the runway to accommodate opening of an airfield on the ice shelf 6 weeks to 2 months earlier than present practice
2. Providing methods or procedures to provide fuel to the consolidated airfield about 6 weeks earlier than what is required for current Pegasus operations
3. Providing an efficient means to supply potable water to the airfield and to dispose of gray and black water generated at the airfield
4. Updating the generator system to meet the demands of the new airfield

Though presently all of these remain as unresolved issues, we see none of them as insurmountable obstacles to establishing a consolidated airfield.

The estimated time needed to implement the consolidated airfield is about 7 years. This includes construction of the new airfield, design and delivery of the new runway support facilities, and suitable resolution of the key factors identified above. At present, no cost has been assigned to the establishment of the consolidated airfield.

Additionally, our report provides an outline of the timeline for operation of the new airfield. The timetable for preparation of the airfield and end of season close out does not differ greatly from current practice. Preparation for WINFLY starts in early July, consistent with current practice. However, we propose that snowcap construction takes place in March and April after station close. This adds additional tasking to the winter crew in com-

parison to current practice but also reduces some tasking from WINFLY and MAINBODY. The remaining operational season contains much of the same tasking as currently required though the timing for some tasks shifts. Most notable is the elimination of runway moves between the Sea Ice Runway and Pegasus Airfield that require movement of buildings and support equipment from Pegasus to Sea Ice following WINFLY and then moving the same facilities back to Pegasus in late November.

References

Antarctic Support Contract (ASC). 2012. *Airfield Operations & Management*. IO-MAN-0002, Version 1. Centennial, CO: Antarctic Support Contract.

Augustine, N. R., T. Allen, C. E. Dorman, H. W. Ducklow, B. Gordon, R. K. Harrison, D. Hartill, G. Jugie, L. J Lanzerotti, D. J. McNabb, R. E. Spearing, and D. H. Wall. 2012. *More and Better Science in Antarctica Through Increased Logistical Effectiveness*. Washington, DC: U.S. Antarctic Program Blue Ribbon Panel.

Blaisdell, G. L., R. M. Lang, G. Crist, K. Kurtti, J. Harbin, and D. Flora. 1998. *Construction, maintenance and operation of a glacial runway, McMurdo Station, Antarctica*. Monograph 98-1. Hanover, NH: U.S. Army Cold Regions Research and Engineering Laboratory.

Buck, A. L. 1981: New equations for computing vapor pressure and enhancement factor. *Journal of Applied Meteorology* 20:1527–1532.

Burzynski, A. 2012. Preliminary analysis of ice shelf movement, Ross Ice Shelf, Antarctica: 1999–2010. Hanover, NH: U.S. Army Engineer Research and Development Center.

Colbeck, S., E. Akitaya, R. Armstrong, H. Gubler, J. Lafeuille, K. Lied, D. McClung, and E. Morris. 1990. *The International classification for seasonal snow on the ground*. Boulder, CO: The International Commission on Snow and Ice, World Data Center A for Glaciology, University of Colorado.

Davis, R. E., and K. Elder. 2000. A Between-Storm Indicator of Avalanche Activity. In *Proceedings of the 2000 International Snow Science Workshop, 1–6 October, Big Sky, Montana*, 135–139. Bozeman, MT: Montana State University Libraries.

Department of the Air Force. 2002. *Design, Construction, Maintenance, and Evaluation of the Pegasus Glacial Ice Runway for Heavy Wheeled Aircraft Operations*. Engineering Technical Letter (ETL) 02-16. Tyndall AFB, FL: Department of the Air Force.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Greene, D. M. McClung, K. Nishimura, P. K. Satyawaii, and S. A. Sokratov. 2009. *The international classification for seasonal snow cover on the ground*. IHP-VII Technical Documents in Hydrology No 83, IACS Contribution No 1. Paris: United Nations Educational, Scientific and Cultural Organization, International Hydrological Programme.

Gubler, H. 1998. A model to determine snow surface properties from remote measurements. In *Proceedings, ISSW'98, International Snow Science Workshop, Washington State Department of Transportation*, 35–48.

Haehnel, R. B., K. Bjella, M. A. Knuth, and L. Barna.2013. *McMurdo consolidated airfields study: Phase I, Basis of design*. ERDC/CRREL TR-13-5. Hanover, NH: U.S. Army Engineer Research and Development Center.

Jordan, R. 1991: *A one-dimensional temperature model for a snow cover: Technical documentation for SNTHERM.89*. CRREL SR-91-16. Hanover, NH: U.S. Army Cold Regions Research and Engineering Laboratory

Kaempfer, T., and M. Schneebeli. 2007. Observation of isothermal metamorphism of new snow and interpretation as a sintering process. *Journal of Geophysical Research* 112:D24101.

Kamata, Y., S. A. Sokratov, and A. Sato. 1999. Temperature and temperature gradient dependence of snow recrystallization in depth hoar snow. *Advances in Cold-Region Thermal Engineering and Sciences, Lecture Notes in Physics* 533:395–402.

Klokov, V. and D. Diemand. 1995. Glaciology of the McMurdo Ice Shelf in the area of air operations. *Contributions to Antarctic Research IV, Antarctic Research Series* 67 175–195.

Manning, K. W., and J. G. Powers. 2011. AMPS Weather Conditions at Potential Alternate Pegasus Sites. Boulder, CO: National Center for Atmospheric Research.

Melendy, T., R. Haehnel, and K. Colby. 2014. Waste Water Handling Proof of Concepts at McMurdo Station, Antarctica. ERDC/CRREL TR-14-17. Hanover, NH: U.S. Army Engineer Research and Development Center.

NYANG. 2011. *LC-130 Emergency Landing Area (Whiteout) Requirements*. Memorandum of Record, New York Air National Guard 109 OSF/OSK, 20 September.

Scanniello, J. 2011a. 2011 Survey Drawing. Centennial, CO: U.S. Antarctic Program, Raytheon Polar Services Company.

Scanniello, J. 2011b. Data from GPS Ground Survey: 1999–2010. Centennial, CO: U.S. Antarctic Program, Raytheon Polar Services Company.

Scanniello, J. 2012. Personal communication. 8 November. Centennial CO: Antarctic Support Contract.

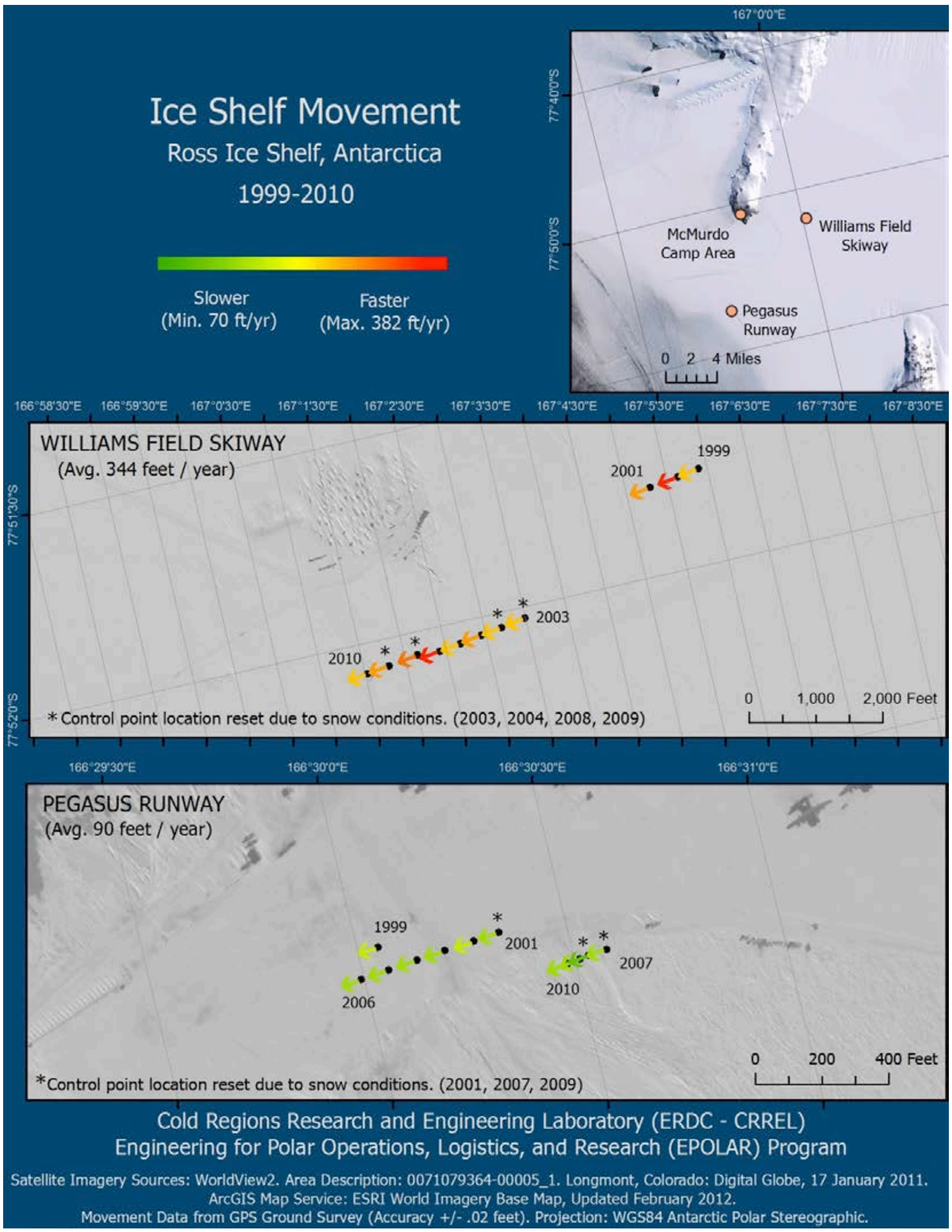
Sturm, M., B. Taras, G. E. Liston, C. Derksen, T. Jonas, and J. Lea. 2010. Estimating snow water equivalent using snow depth data and climate classes. *Journal of Hydrometrology* 11:1380–1394.

Thuma, R., and D. Gregory. 2012. Single Airfield Complex (SAC) Airfield Master Plan Study: 90% review meeting. Presentation for the National Science Foundation, 12 December. Springfield, IL: Crawford, Murphy & Tilly, Inc.

Thuma, R., and D. Gregory. 2013. *Airfield Master Plan Development for a Single Airfield Complex (SAC): McMurdo, Antarctica*. Springfield, IL: Crawford, Murphy & Tilly, Inc.

Appendix A: Ice Shelf Movement

Figure A1. Preliminary analysis of ice shelf movement, Ross Ice Shelf, Antarctica: 1999–2010 (Burzynski 2012). GPS ground survey collected by Scanniello (2011a).

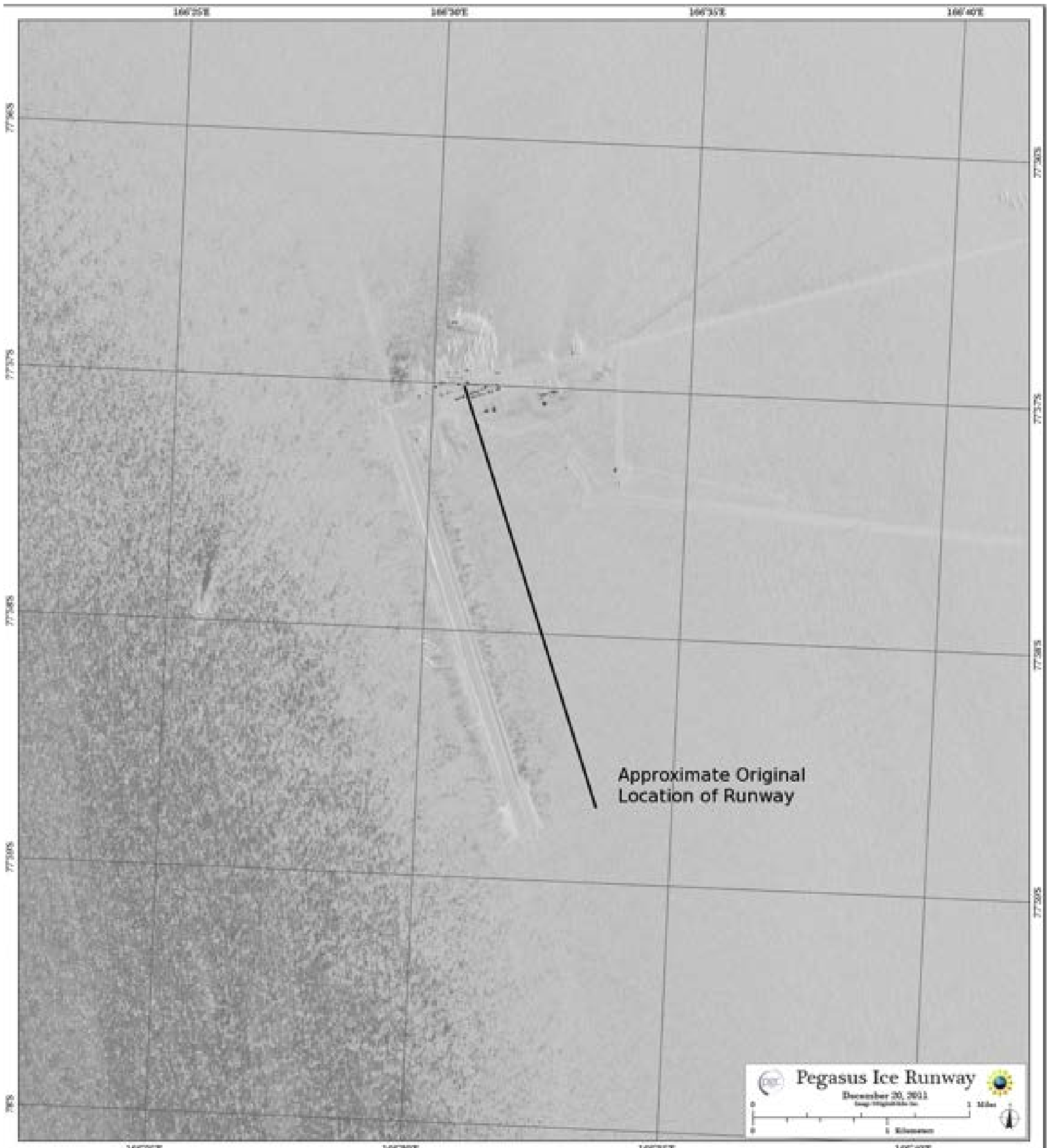


Appendix B: Evaluation of Satellite Images of Pegasus Airfield

To assess over time where the white ice runway is in relation to the transition zone between net accumulation and net ablation regions of the ice shelf, the Polar Geospatial Center, University of Minnesota, provided to CRREL satellite images of the region surrounding the Pegasus airfield that date back to 2002. Blaisdell et al. (1998) described this transition region as marked by roughly uniform snow depth and identified the western edge "of essentially continuous snow cover in late December" as the location for placement of the Pegasus runway. Construction of the runway began along this edge in 1990–91; the runway was oriented roughly north to south along the direction of this transition zone. Since completion and certification of the runway in 1992–93, the runway has remained in this location on the Ross Ice Shelf, drifting west with the ice shelf at a rate of about 100 ft/year (30 m/year). At that rate of drift, the Pegasus runway is now approximately 2000 ft (610 m) west of its original location as shown in Figure B1.

It is expected that the line marking this transition zone from net ablation to net accumulation would on average remain stationary in time with slight annual deviations east and west due to yearly variations in climatic conditions. As such, one would expect the Pegasus airfield to move west out of this transition zone and into a net ablation zone over time and that periodically the runway would need to be relocated east to stay in a region where ample supply of snow is available for establishing a snowcap to protect the runway yet not so much snow that rapid establishment of a hard landing surface for wheeled aircraft is impractical.

Figure B1. Satellite image (20 December 2011) of the Pegasus airfield. The black line indicates the approximate original geographic location of the white ice runway when it was established in 1991–93. (Image provided by the Polar Geospatial Center, University of Minnesota. Satellite image source: Digital Globe WorldView-1 satellite, Panchromatic, 0.5m spatial resolution.)



Approach

Using the satellite images provided, we drew a line on each image to mark the approximate west edge of the continuous snow cover for the last 10

years. Table B1 lists the dates of the images provided. The images used in this analysis are reproduced in the end of this Appendix*.

Images were not available for all of the 10 years, and an obvious gap in the data is apparent between 2002 and 2005. Also, some images are of higher quality than others. For example, in Figure B3, the northern end of the runway is partially obscured by clouds and in Figure B4 part of the runway was not included in the acquired image. Nevertheless, we used what data we could from the images provided.

Following the guidance provided by Blaisdell et al. (1998), we preferred images that were acquired in December as these showed the eastern limit of this edge for that season. As there were not always images available from December, the earliest acceptable images we used for this analysis were from 1 November. Based on this, we did not use two of the images provided as they were acquired during October. These images are marked with (*) in Table B1.

The images provided in GeoPDF format by the Polar Geospatial Center were orthorectified† and projected in WGS84 Antarctic Polar Stereographic projection so we could extract distances from the images using Geographic Information System tools. Using these tools, we measured the distance from the centerline of the runway to the eastern limit of the snow–ice transition.

We determined the measurements by first drawing a centerline along the 10,000 ft length of the runway (but not including the 1000 ft overrun at the south end of the runway). Then we drew a polyline that indicated the edge of the continuous snow cover (e.g., Figure B3). This line could be on the west or east side of the runway (or in principal it could cross the runway, though this was not the case for any of the images shown). Then we measured the distance from the centerline to the polyline, indicating the edge of the continuous snow at three locations along the runway: the runway threshold (station 00+00), the runway mid length (station 50+00, 5000 ft or 1524 m), and the end of the runway (station 100+00, 10,000 ft

* The images provided were of much higher resolution that the images reproduced in this document. The Imagery section at the end of this appendix provides the spatial resolution and the source information for each image.

† The images were orthrectified using a 660 ft (200 m) resolution digital elevation model. The positional accuracy of the orthorectified image is approximately ±115 ft (35 m).

or 3048 m). Positive distances indicate the edge of the continuous snow is west of the runway while negative distances indicate the edge is east of the runway. Table B1 tabulates measurements.

Table B1. Dates of satellite images provided by the Polar Geospatial Center, University of Minnesota, and the distance to the snow edge in feet (meters) from the centerline of the runway taken at 3 stations along the runway, 0, 5000, and 10000 ft. Positive values are west of the runway while negative values are east of the runway.

	Snow Edge Relative to the Runway Centerline, ft (m)		
Image Date	**00+00 (0 m)**	**50+00 (1524 m)**	**100+00 (3048 m)**
25 Dec 2002	4500 (1370)	3740 (1140)	2620 (799)
31 Oct 2005*	N/A	N/A	N/A
6 Dec 2006	n.a.	3970 (1210)	3280 (1000)
15 Dec 2007	−1690 (−515)	−1530 (−466)	−1240 (−378)
12 Oct 2008*	N/A	N/A	N/A
9 Nov 2009	−640 (−195)	−1380 (−421)	−1550 (−472)
17 Dec 2010	−3630 (−1110)	−3340 (−1020)	−3070 (−936)
20 Dec 2011	−2040 (−622)	−1190 (−363)	−1130 (−344)

* Images not used in the analysis because they were acquired before 1 November of the year.

n.a. = Data not available because image did not cover that region.

N/A = Measurements not taken for these images.

Results and discussion

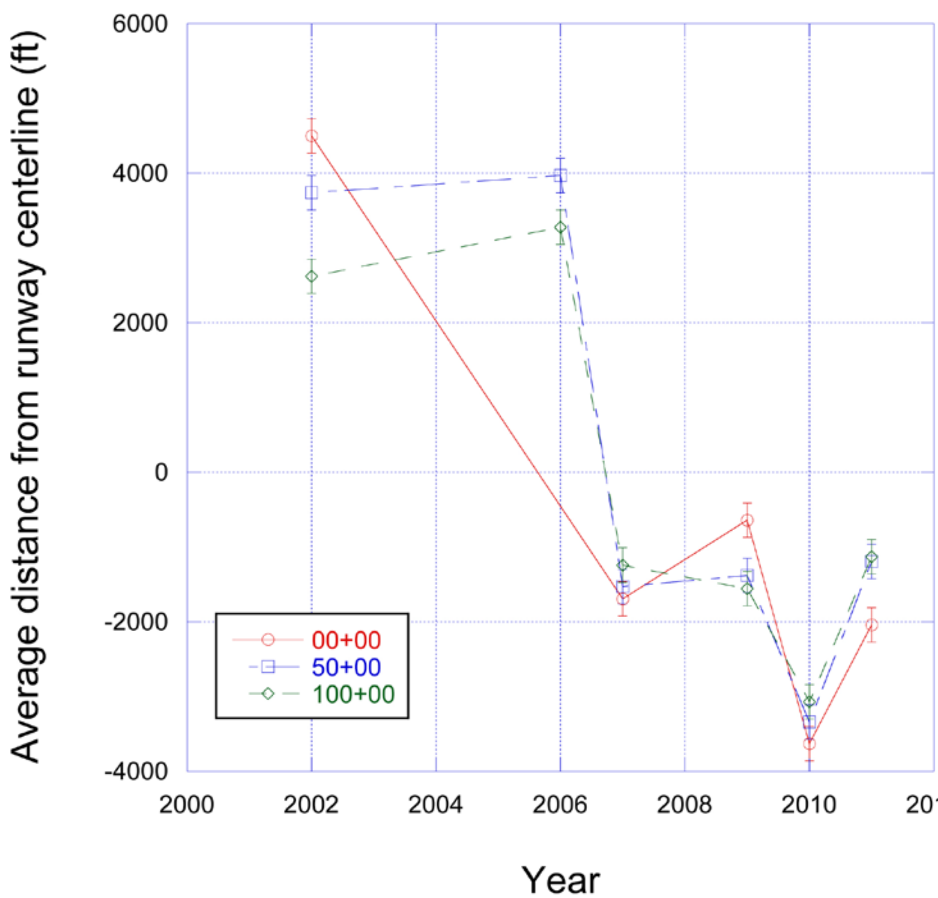
Figure B2 provides a summary of the results given in Table B1. This shows that for 2002 and 2006, the edge of the continuous snow was typically about 3500 ft west of the runway. Unfortunately, there is no data between these dates; so we are unable to evaluate any annual variations during this time period.

Between 2006 and 2007 there is an abrupt shift from the west side of the runway to the east side. It is unclear as to the cause of this. It is possible that it may be a result of a local influence of the runway’s presence on the ice and that the progression of the snow edge is very slow until it gets close to the runway, and then the local influence of the runway causes the edge to “jump” to the east side.

For the data from 2007 to the most recent season (2011–12), there appears to be a very slow and noisy trend of increasing distance between the location of the edge of the continuous snow and the runway, a result of the runway moving west of what one would expect to be on average a stationary transition zone. If a trend line is fit through these last 4 data points

(2007–11), one finds the average rate of progression is about 160 ft/year, almost twice the observed rate of movement of the ice shelf in this region. However, this is highly biased by the rate computed for the north end of the runway (266 ft/year). The rates at stations 50+00 and 100+00 are 91 and 125 ft/year, which are in much better agreement with the observed movement of the ice shelf. The scatter associated with these values can come from annual variations in temperature and precipitation, image quality, and the ability to resolve the precise edge of the continuous snow region. The latter cause is particularly acute near the north end of the runway as the airfield town site makes it difficult to determine the snow edge, and albedo modification due to the human influence at the town site may also influence the migration of the edge in that region. Therefore, if we ignore the rate of progression at the north end of the runway, we find that, based on the more recent data (2007–11), the runway appears to be moving beyond the edge of the continuous snow at a rate that is consistent with the movement of the ice shelf.

Figure B2. Distance from the centerline of the runway to the edge of the continuous snow. Positive values are west of the centerline while negative values indicate that the continuous snow edge is east of the centerline of the runway.



Based on the direction of movement extracted from the satellite images below and assuming an average rate of ice shelf movement of 100 ft/year, in Figure B1, we have drawn the approximate location of the Pegasus runway established in 1991–93. This is an approximate location of where we recommend relocating the white ice runway. Based on experience with the Pegasus airfield up to this point, we could expect the new runway at Pegasus to function for 20 years or more after relocation before it would need to be moved again.

These observations are taken together with a recent coring survey of the subsurface stratigraphy between the white ice runway and the skiway to the east. The survey shows that at a distance of 1500 ft east of the runway, the glacial ice is about 5 in. below the snow surface; but at 2000 ft east of the runway, the glacial ice lies under 41 in. of snow.

This indicates that somewhere between 1500 and 2000 ft east of the present location of the white ice runway lies the east edge of the transition zone between net accumulation and net ablation. This is close to the original geographic location of the white ice runway indicated in Figure B1. As this survey was acquired along a single linear transect extending between the runway and skiway, further work is required to understand the stratigraphy along the east side of the runway extending along its entire length. This data could then help to determine the optimal location for relocating the runway.

Conclusions and recommendations

Based on this study, it appears that the present white ice runway has drifted outside the transition zone between the net accumulation and net ablation zones on the Ross Ice Shelf. This may be part of the cause for reduced strengths of the white ice runway during the warmest period of the summer season as the runway now seems to be located at the edge of the net ablation zone. This is a natural consequence of the runway moving with the ice shelf. The approximate distance that the runway has moved over this time is about 2000 ft.

Based on this, we recommend conducting a field survey of the subsurface stratigraphy along the east side of the runway to determine the east edge of the transition zone. We can then use this information to determine the optimal site for relocating the white ice runway and for placing it back within the transition zone.

Imagery

Figure B3. Image acquired 25 December 2002 and provided by Polar Geospatial Center, University of Minnesota. The red line at the left side indicates the approximate edge of the continuous snow cover. The runway centerline and stations are also indicated in the figure. (Image source: Digital Globe Quickbird 2 satellite, multispectral [RGB], 2.5 m spatial resolution.)

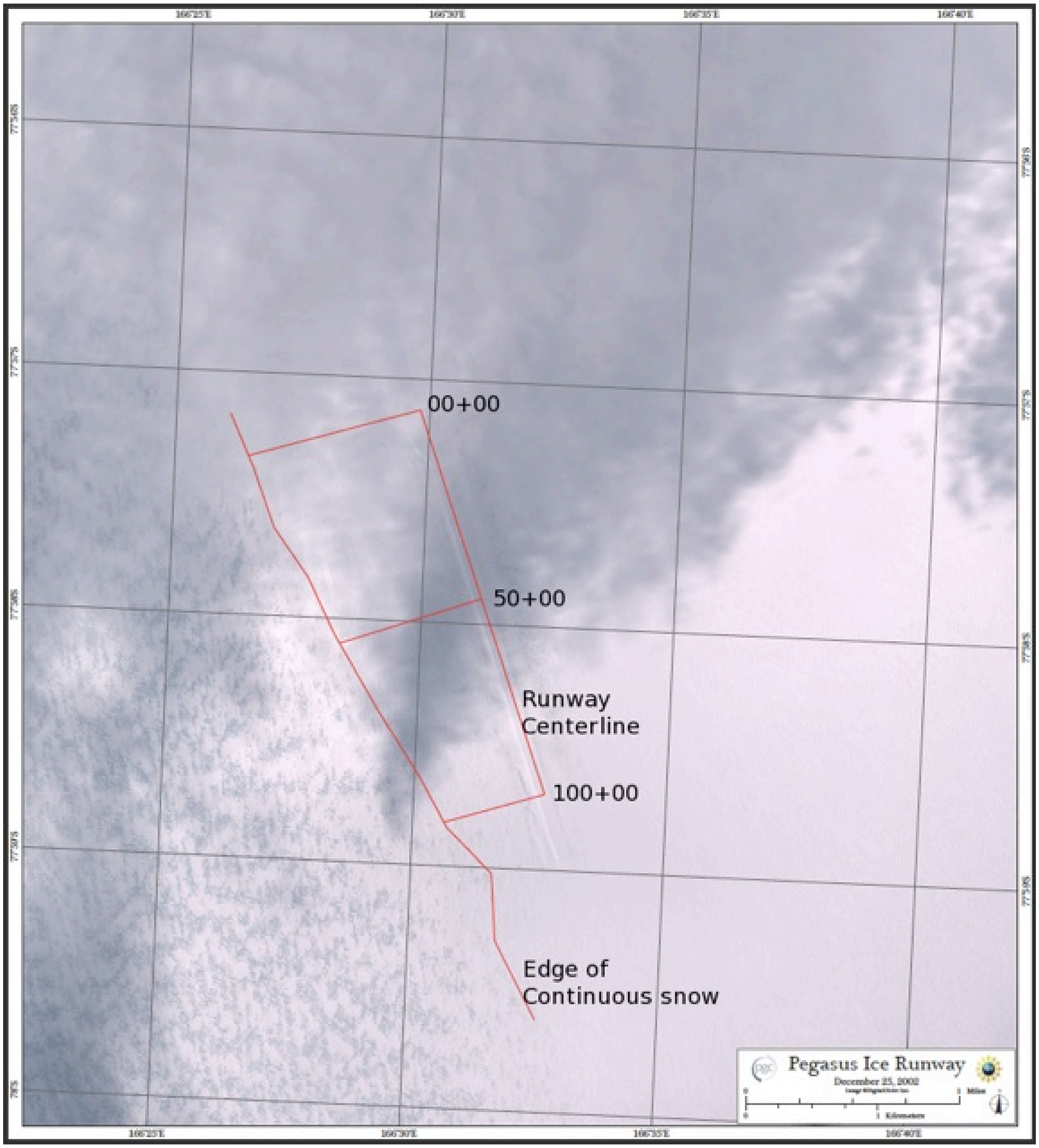


Figure B4. Image acquired 6 December 2006 and provided by Polar Geospatial Center, University of Minnesota. (Image source: Digital Globe Quickbird 2 satellite, multispectral (RGB), 2.5 m spatial resolution.)

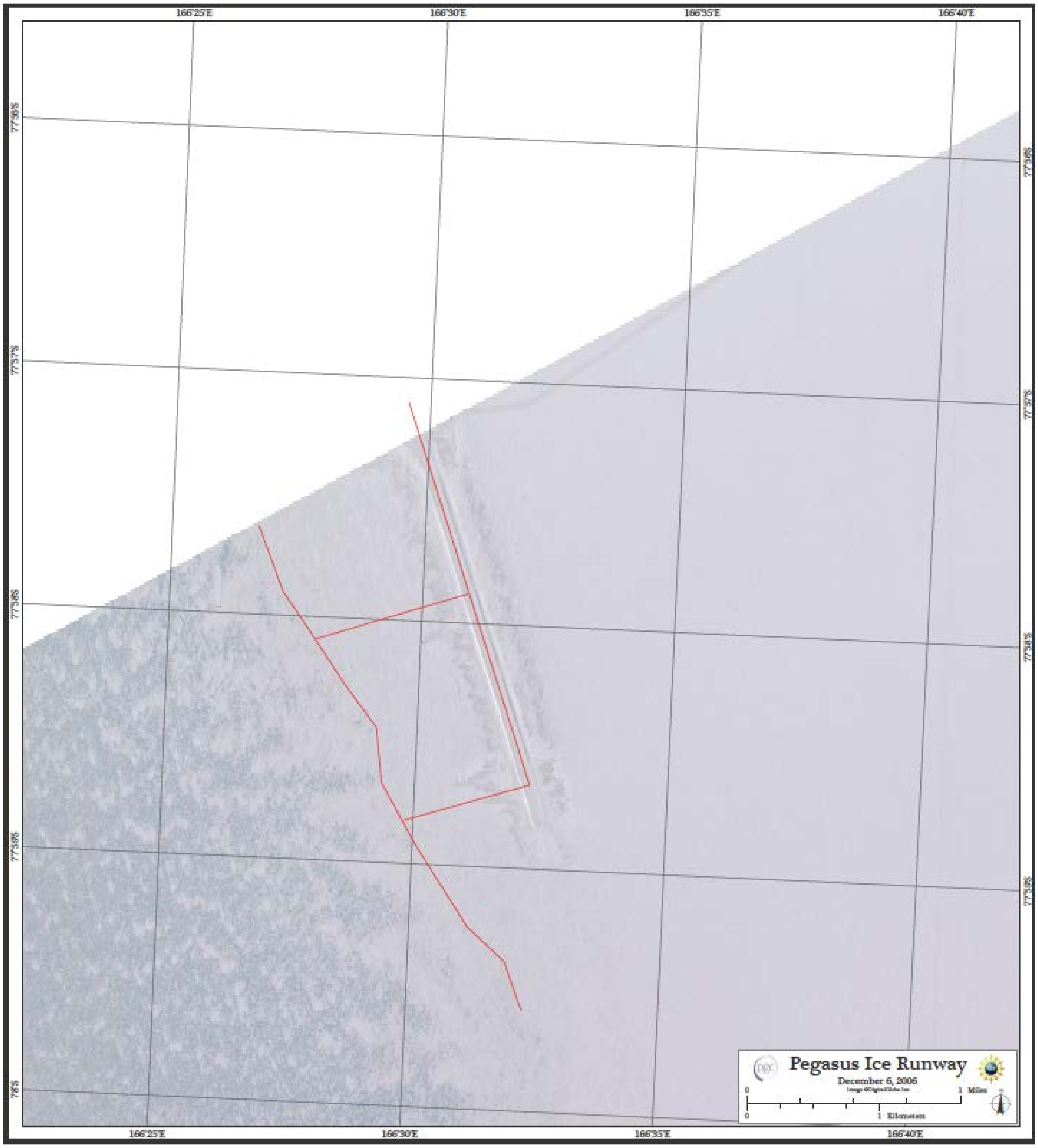


Figure B5. Image acquired 15 December 2007 and provided by Polar Geospatial Center, University of Minnesota. (Image source: Digital Globe Quickbird 2 satellite, multispectral [RGB], 2.4 m spatial resolution.)

Figure B6. Image acquired 5 November 2009 and provided by Polar Geospatial Center, University of Minnesota. (Image source: Digital Globe WorldView-1 satellite, Panchromatic, 0.5 m spatial resolution.)

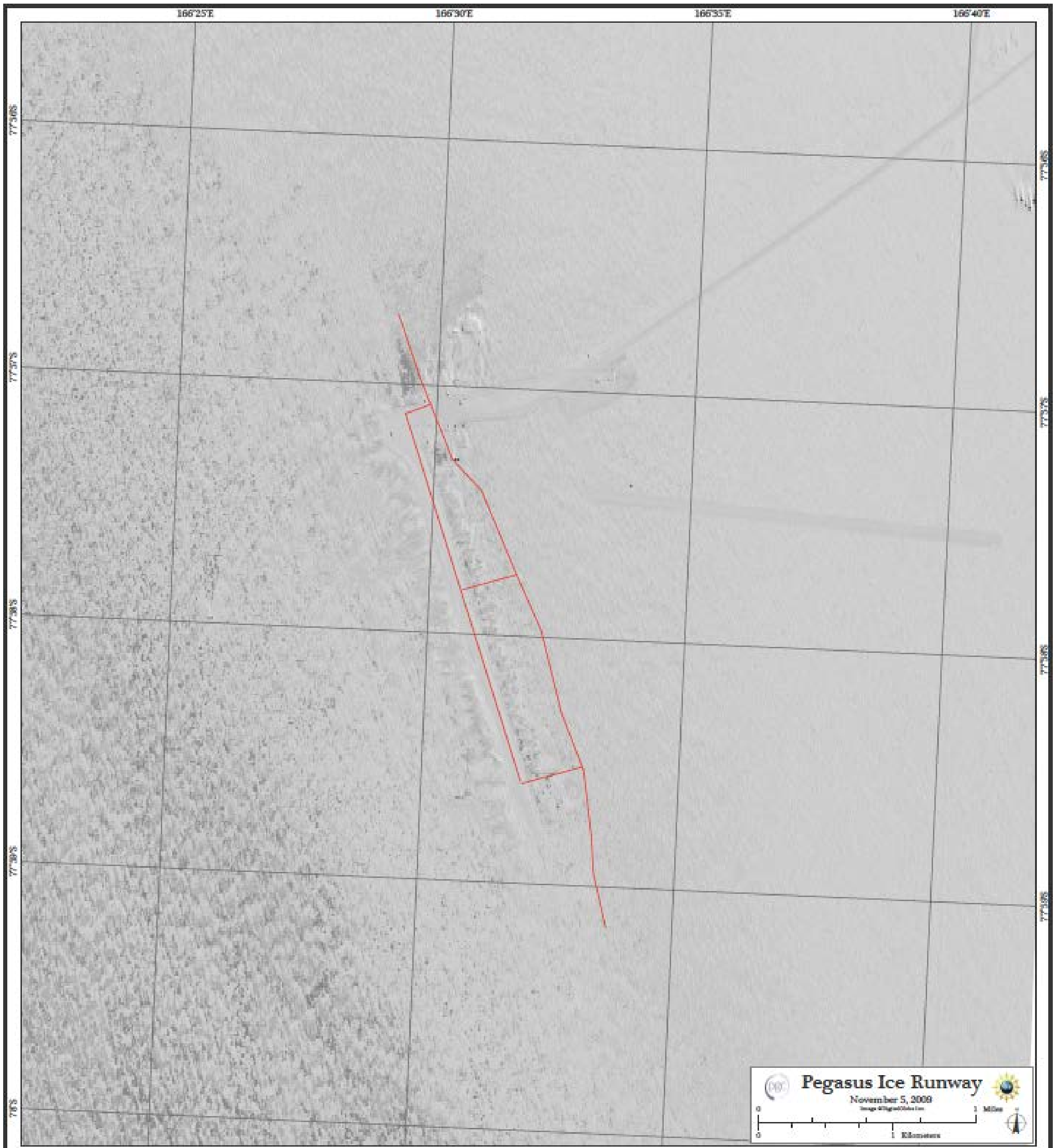


Figure B7. Image acquired 17 December 2010 and provided by Polar Geospatial Center, University of Minnesota. (Image source: Digital Globe WorldView-2 satellite, multispectral [RGB], 2 m spatial resolution.)

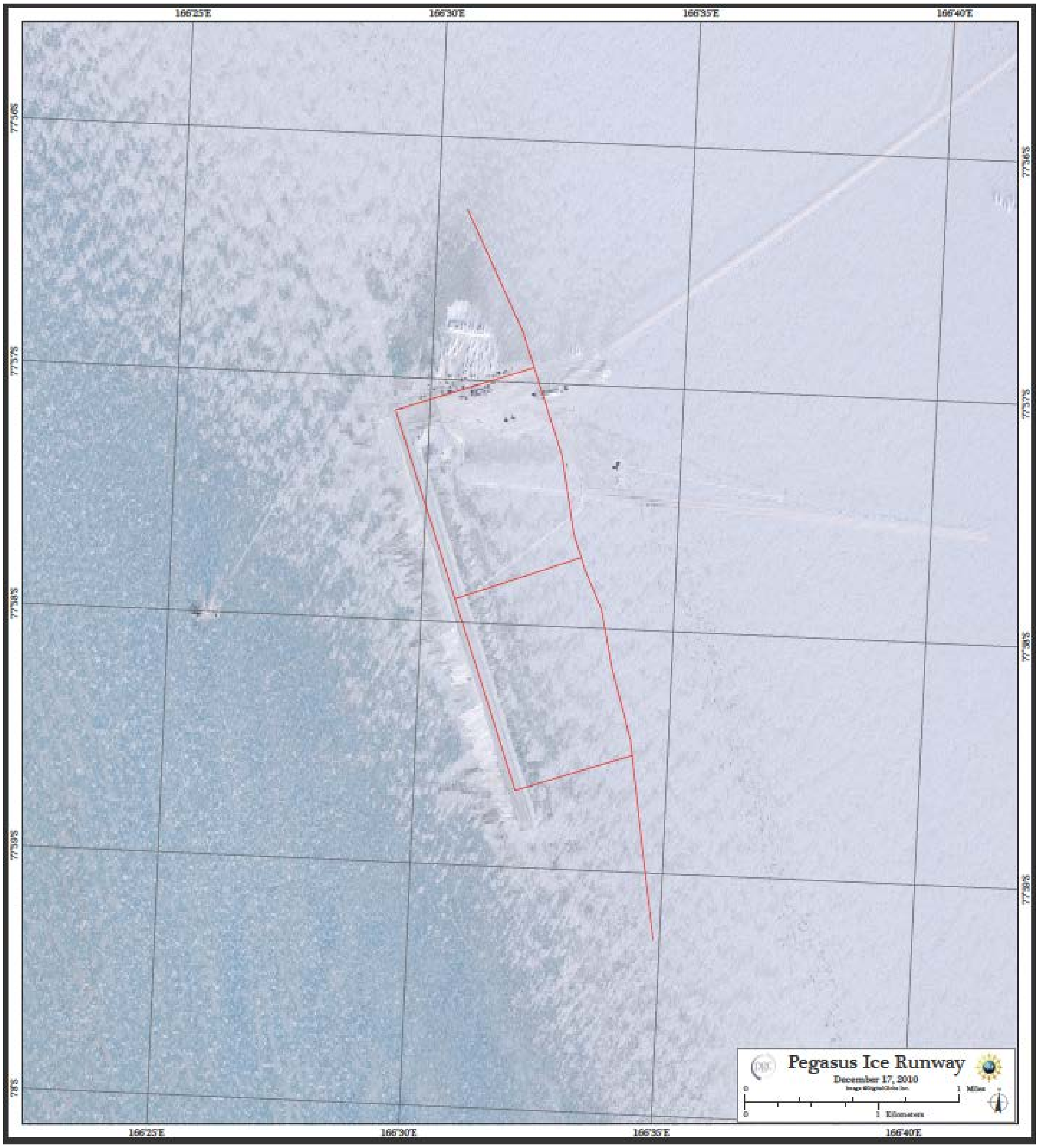
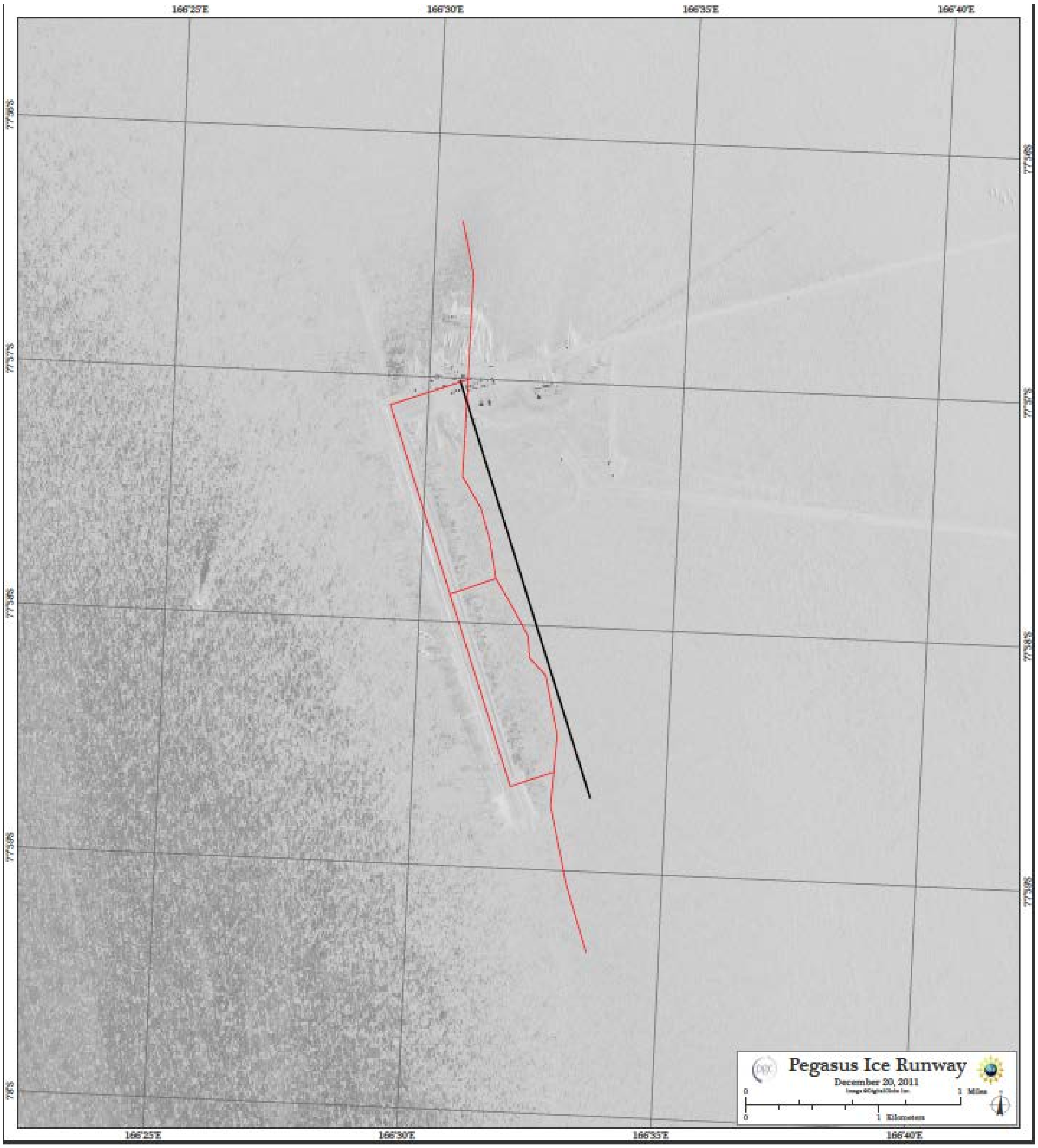


Figure B8. Image acquired 20 December 2011 and provided by Polar Geospatial Center, University of Minnesota. The black line east of the runway indicates the approximate location of the original runway constructed in 1991–93 relative to the runway in 2011. (Image source: Digital Globe WorldView-1 satellite, Panchromatic, 0.5 m spatial resolution.)



Appendix C: Whiteout Landing Area Requirements

NEW YORK AIR NATIONAL GUARD
109 OSF/OSK
1 AIR NATIONAL GUARD ROAD
SCOTIA NEW YORK 12302-9752

20 September 2011

MEMORANDUM FOR RECORD

FROM: 109 OSF/OSK

SUBJECT: LC-130 EMERGENCY LANDING AREA (WHITEOUT) REQUIREMENTS

Requirements for a LC-130 Emergency Landing Area (or Whiteout Area) are difficult to quantify. As an option of last resort, the Whiteout Area mostly needs to satisfy common sense requirements:

The Whiteout Area Will:

1. Be free of manmade obstacles, with the exception of occasional low (less than 60 inches) frangible obstacles (such as bamboo marking flags).
2. Consist of relatively smooth, uniform snow surface terrain, with no perceivable slope or significant terrain features (to include pressure ridges and rises associated with local islands or mountains) within the area identified for safe landing.
3. Allow for determination of area boundaries by Aircrew through at least two means or navigation aids (to include Global Positioning System, and TACAN).
4. Be located within the greater terminal area of the primary landing airfield. Practically, within approximately 40 NM of the primary airfield at it it's furthest extent.
5. Be approved (certified for use) by the Airfield Manager and Air Expeditionary Group Commander (or their representative) prior to major LC-130 operations.

The Whiteout Area Should:

1. Include a maneuvering area (or buffer zone) beyond the limits of the defined area for safe landing, where the aircraft can safely maneuver at low altitudes (down to approximately 300 ft) and remain clear of terrain and large obstacles. Ideally this area would be at least 1 NM on all sides. Though it is preferred that no obstructions, such as buildings, would be within the maneuvering area, obstructions would be allowable if they do not exceed 50ft in height and they exist prior to establishment of the maneuvering area. Any such buildings must be marked on approach plates and the height of the building clearly noted. Furthermore, obstructions must be sparse, with the maneuvering area being largely free of obstacles, frangible or otherwise.
2. Be clear of vehicles and personnel at all times. This restriction would eliminate roads / traverse routes.
3. Be clear of ***all*** obstacles, frangible or otherwise.
4. Allow for direct flight between the airfield and the boundary of the safe area at low altitude.
5. Be of sufficient dimensions to allow for safe landing in any direction and safe takeoff in the direction of the predominant wind. The area, at a minimum, should encompass a circle with a circumference of 2 NM.
6. Encompass a landing area which is free of sastrugi or uneven snow surfaces (ideally, variations in surface elevation should be less than 4 inches over 20 feet).
7. Be easily accessible by emergency vehicles and refueling capability.
8. Allow for a manner of emergency shelter to accommodate, at a minimum, a crew of 6 people.

//SIGNED//
David LaFrance, Major, NYANG
109 OSF/OSK (TACTICS)
D: 344-2640

Appendix D: Proposed Alternative Locations for the Whiteout Landing Area

Possible locations that stakeholders initially identified for the WO landing area (Figure D1) were east of the current Pegasus skiway (option 1) and south of the Pegasus white ice runway (option 2). Though both of these options can be beaconed using the TACAN at Pegasus, further review of these sites showed they were generally not acceptable as they do not allow for maneuvering areas and the terrain is not smooth. Both of these issues are discussed below.

For options 1 and 2, the maneuvering areas would be restricted in size due to the proximity of White and Black islands (bottom of Figure D1). This is especially true for option 2, which is nestled in between both islands. Option 1 also overlaps White Island and the creases or “rollers” in the glacial ice off the point of White Island (south east corner of option 1). This issue could be resolved by rotating option 1 toward the north, using the Pegasus TACAN as the pivot point, thereby moving the entire WO landing area out of these trouble spots. However, this still leaves little room for clear maneuvering areas with the Long-duration Balloon facility to the north and White Island to the south.

Furthermore, the landing surfaces contained within the indicated WO landing area for both of these options are rough. For option 2, much of the landing area is ice that has undulations; and during the warmer parts of the summer, subsurface melt pools are present. Option 1 has a better surface. The east side has smooth featureless snow covered terrain. However, on the west side, the snow surface is windblown, harder, and has more surface relief, making this a very rough surface to land on, even with skis. Therefore, due to these considerations, we do not consider it feasible to establish WO landing areas close in to the Pegasus airfield.

Figure D1. Possible alternate whiteout landing areas, options 1 and 2 (drawing provided by Raytheon Polar Services Corporation).

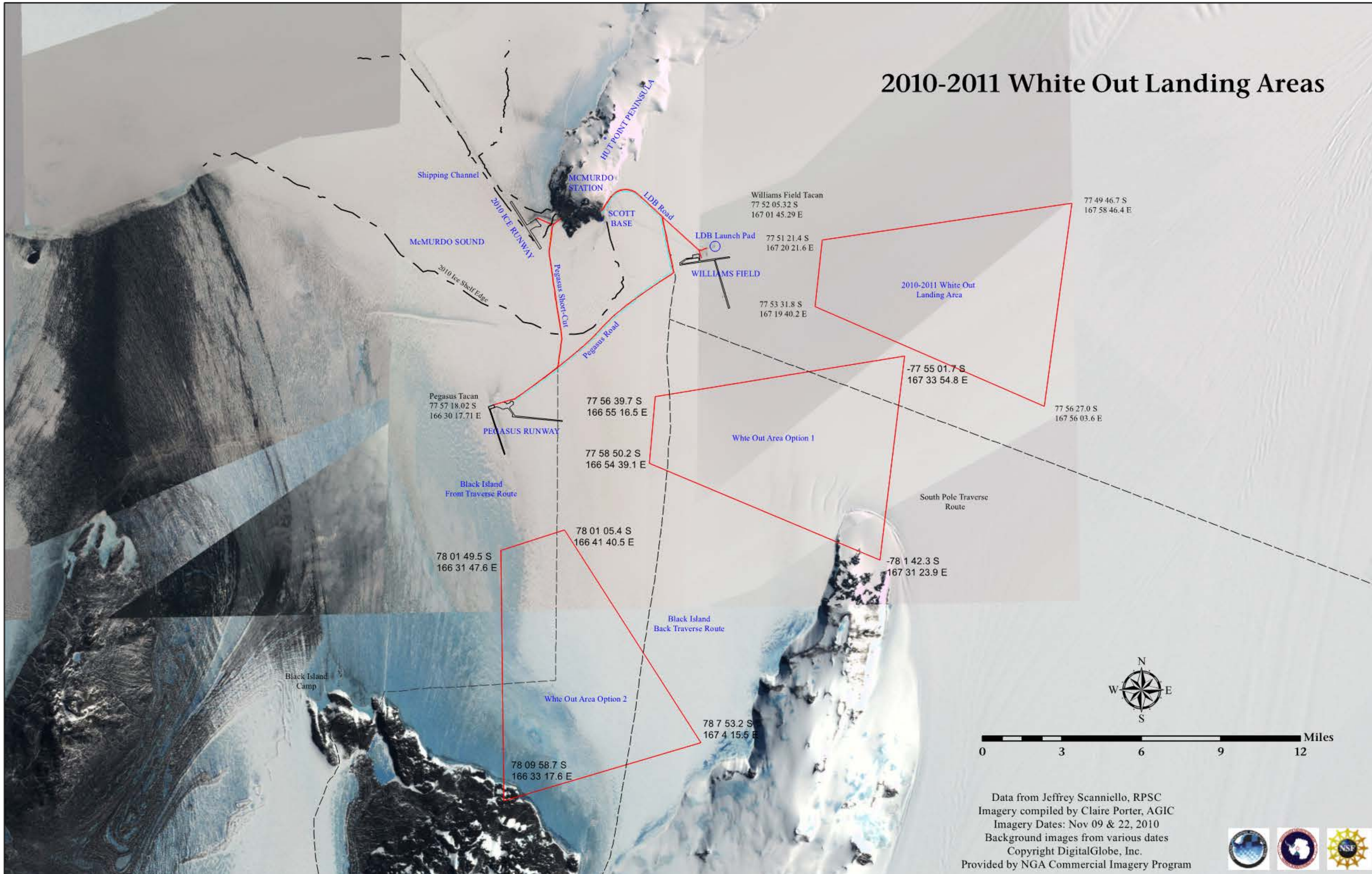
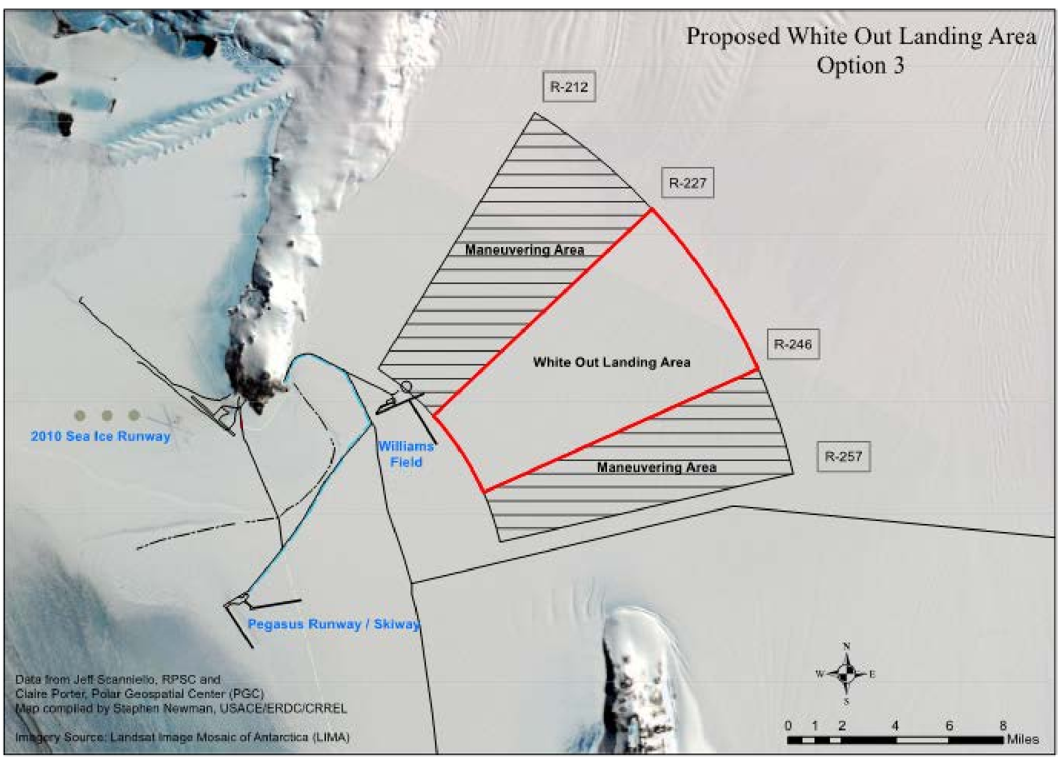


Figure D2 depicts a third option. This is a hybrid between the original WO area and option 1. In this option, the WO landing area is still on the smooth, flat snow associated with the windless bight. However, it is farther west and is closer to the existing Williams Field that is re-established annually and is maintained with the minimal NAVAIDs needed for emergency flight diverts. The WO area shown in Figure D2 is also beaconed using the Pegasus TACAN, rather than the one used at Williams Field allowing approach to the WO landing area to be facilitated with the TACAN used for standard flight operations. This option does move the WO landing area about 2 n.m. closer to the consolidated airfield, yet this is still quite remote.

Figure D2. Revised whiteout landing area (option 3) that moves the area closer to the Pegasus airfield.



It is debatable if there is any advantage to option 3 over the current WO landing area. A TACAN will still need to be maintained at Williams Field as long as that airfield is maintained to provide a weather divert landing site for ski-equipped aircraft. Therefore we are unable to eliminate the need for two TACANs. Second, for both designs (existing and option 3), the WO landing area is remote from the consolidated airfield; and a reduc-

tion in distance from about 10 to 8 n.m. is likely not sufficient on its own merit to justify a change. Therefore, for the present, the WO landing area will remain at its current location.

Appendix E: Notes on Snow Grain Growth and Strengthening, Pegasus White Ice Runway at McMurdo, Antarctica*

This note has the purpose of providing some context in terms of what we know and can deduce, based on temperature records from McMurdo, about sintering, snow grain growth, and general strengthening. Snow temperature gradients drive sintering and coarsening up to a threshold beyond which kinetic growth of grains begins, occurring at the expense of the associated sintering. Temperature, more than the vapor pressure gradient, can play the lead role in grain growth specific to approaching the threshold of the kinetic growth regime (Kamata et al. 1999) while the vapor flux and perhaps ice-surface diffusion play the key roles in sintering (e.g., Kaempfer and Schneebeli 2007). Accordingly, a key to gaining insights and some understanding of the conditions at Pegasus rely on examining the temperatures and temperature gradients that might exist at or near the runway.

Based on simple observations, Davis and Elder (2000) showed that an index of vapor pressure gradient in snow correlates well with grain growth modeled using the validated snow model SNTHERM (Jordan 1991). Davis and Elder (2000) proposed that the minimum daily air temperature forms a reasonable surrogate for minimum surface temperature of dry snow near the site of the air temperature measurement. Further, I assumed that the temperature midway between the minimum and the maximum daily air temperatures represents a crude approximation of dry snow temperature near the diurnal damping depth, several centimeters below the surface. With these assumptions, we can gain some insight on the subsurface temperature gradients, which drive grain growth and sintering.

The Vapor Gradient Index (VGI) represents a cumulative expression of temperature gradient effects on the potential vapor gradient during periods with no significant snowfall. To formulate the VGI, we calculated an

* Appendix by Dr. Robert Davis, CRREL, 18 July 2012.

individual daily interim value VGI' based on the difference in saturation vapor pressure between the two temperatures.

Buck (1981) formulated modified expressions of the Clausius-Clapeyron relation to estimate the saturation vapor pressure, $P_{v,sat}$ (mb), based on temperature, T (0°C):

$$P_{v,sat} = 6.138\ e^{22.452\ T/(272.55\ +\ T)}.$$

The current-day value of the interim vapor pressure gradient VGI' comes from the difference between $P_{v,sat}$ at the two temperatures:

$$VGI' = P_{v,sat}\ (T_{min}) - P_{v,sat}\ ((T_{min} - T_{max})/2).$$

Over time the index accumulates:

$$VGI_{today} = VGI_{yesterday} + VGI'.$$

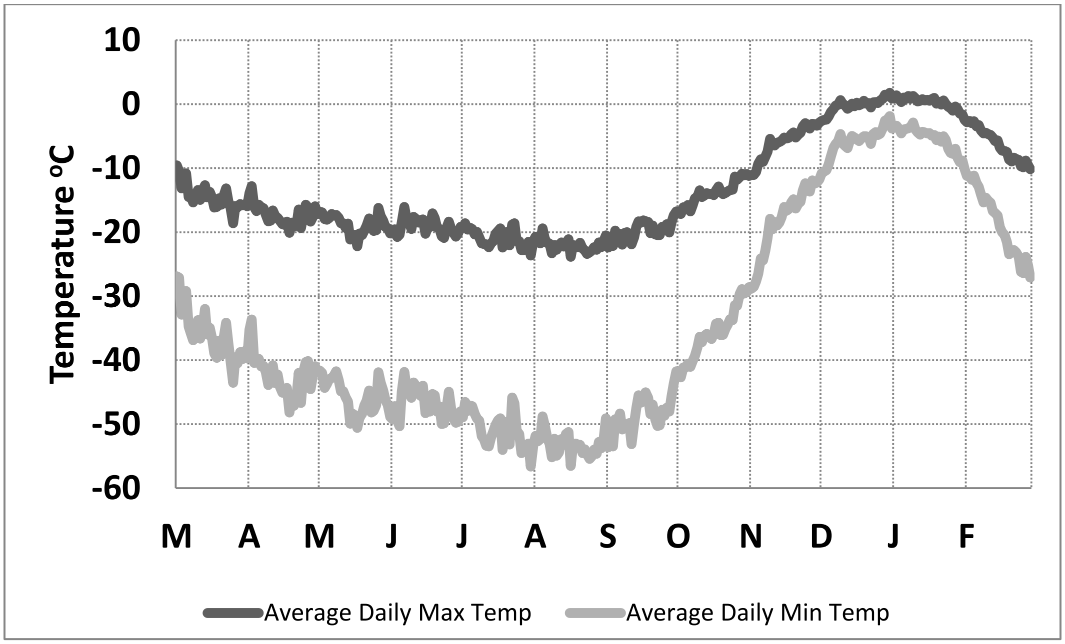
During storms, VGI is constant at the last value before snowfall. The first day after snowfall, VGI = VGI' for the day. In other words, the VGI comes from the cumulative sum of the daily values of VGI' every day. Functionally, VGI has similarity to the estimation of near surface gradients of vapor density proposed by Gubler (1998), except that Gubler's method requires much more measurement support and provides more frequent estimates of near-surface processes.

Applying this conceptual approach to snow and firn on the Pegasus runway, we can examine potential strength change due to sintering and grain growth during different parts of the year. The analysis below used the mean daily maximum and mean daily minimum temperatures measured at McMurdo Station as surrogates for the conditions over the runway.

Initial inspection of the temperature data, shown in Figure E1, suggests some counteracting factors. The surrogate temperature gradients (the temperature difference between the minimum and maximum daily air temperature) during the winter appear much greater than during the summer, reaching a maximum by March. The proxy values do not approach the threshold commonly accepted for robust kinetic growth but rather indicate conditions conducive to coarsening and associated sintering.

Collectively, this implies strengthening. The mean temperatures during winter months, around −35°C, suggest not a lot of grain growth takes place.

Figure E1. Mean maximum and minimum daily air temperatures observed at McMurdo Station, Antarctica.



Using the VGI, we can see the overriding effect of temperature in Figure E2, by comparing it with Figure E1. This figure shows that we should expect much of the metamorphic activity to take place during the warmer months.

To assess the value of preparing the compaction and grooming cycles starting at the onset of winter rather than in spring, we compare the cumulative value of the VGI for March 1 and November 1 starts, assuming VGI is directly related to snowcap strength. In Figure E3, we can see the differences between preparing the snowcap, mainly related to slow sintering processes over winter. In particular, the VGI on 1 December is approximately 4 times higher when allowed to sinter starting on 1 March as compared to starting the sintering process on 1 November.

This analysis suggests that one would not necessarily want to do much to the snowcap over the winter because the natural sintering processes fol-

lowing compaction of the snow in early March should provide the required strength increase.

Figure E2. Daily values of the VGI.

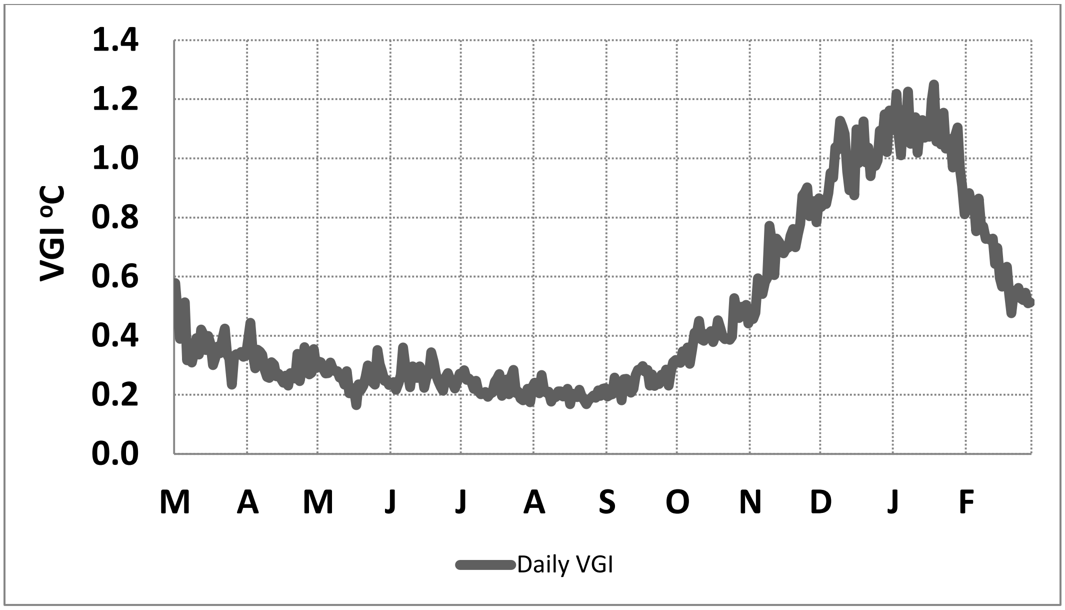
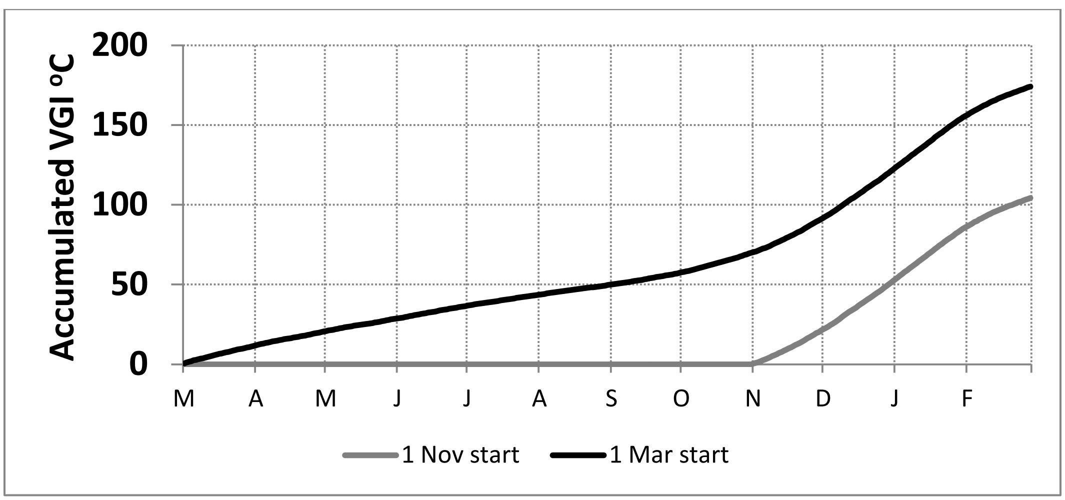
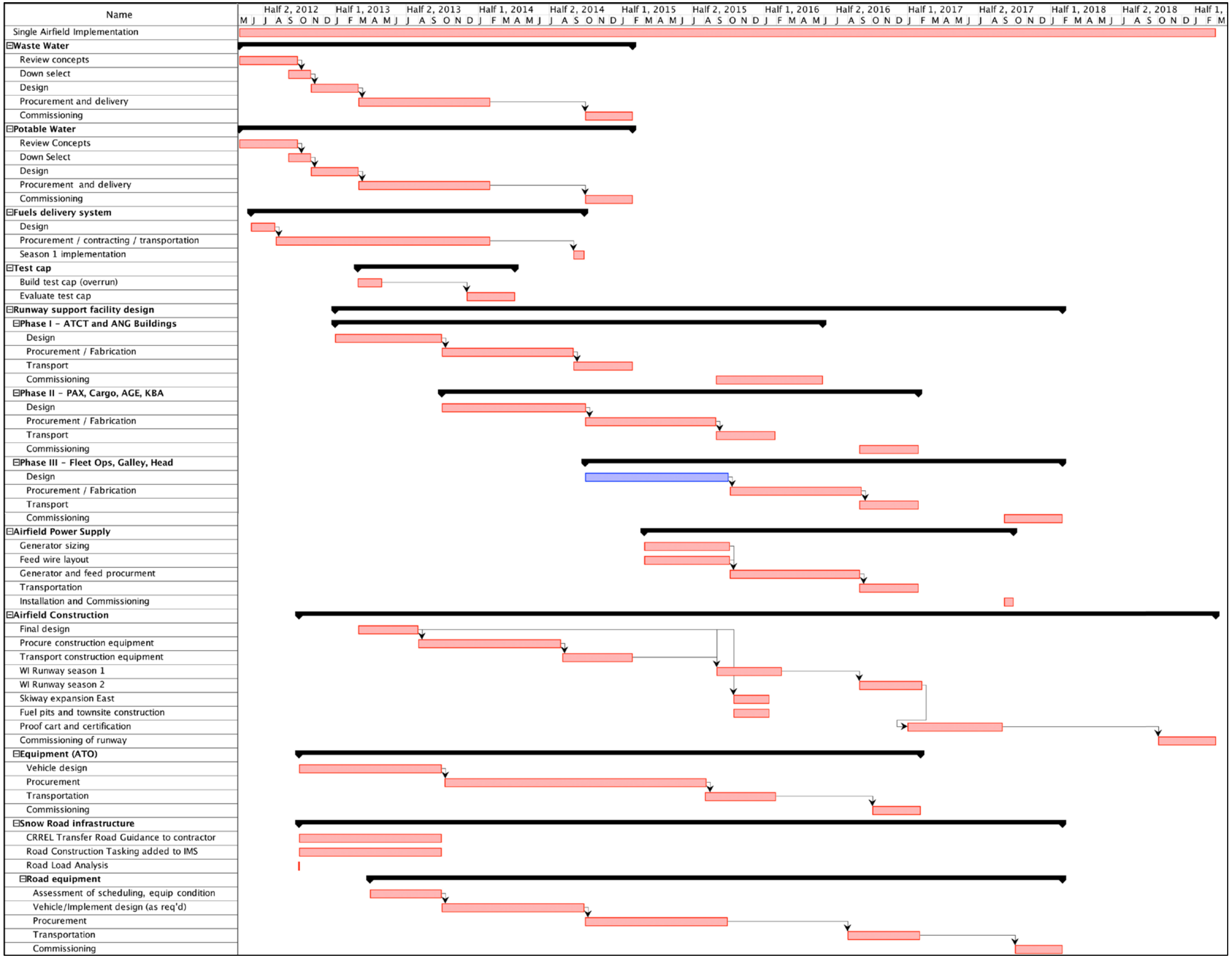


Figure E.3. Cumulative VGI starting on March 1 and November 1.



Appendix F: Draft Consolidated Airfield Implementation Schedule


Name
Half 2, 2012
Half 1, 2013
Half 2, 2013
Half 1, 2014
Half 2, 2014
Half 1, 2015
Half 2, 2015
Half 1, 2016
Half 2, 2016
Half 1, 2017
Half 2, 2017
Half 1, 2018
Half 2, 2018
Half 1,
Single Airfield Implementation
Waste Water
Review concepts
Down select
Design
Procurement and delivery
Commissioning
Potable Water
Review Concepts
Down Select
Design
Procurement and delivery
Commissioning
Fuels delivery system
Design
Procurement / contracting / transportation
Season 1 implementation
Test cap
Build test cap (overrun)
Evaluate test cap
Runway support facility design
Phase I – ATCT and ANG Buildings
Design
Procurement / Fabrication
Transport
Commissioning
Phase II – PAX, Cargo, AGE, KBA
Design
Procurement / Fabrication
Transport
Commissioning
Phase III – Fleet Ops, Galley, Head
Design
Procurement / Fabrication
Transport
Commissioning
Airfield Power Supply
Generator sizing
Feed wire layout
Generator and feed procurment
Transportation
Installation and Commissioning
Airfield Construction
Final design
Procure construction equipment
Transport construction equipment
WI Runway season 1
WI Runway season 2
Skiway expansion East
Fuel pits and townsite construction
Proof cart and certification
Commissioning of runway
Equipment (ATO)
Vehicle design
Procurement
Transportation
Commissioning
Snow Road infrastructure
CRREL Transfer Road Guidance to contractor
Road Construction Tasking added to IMS
Road Load Analysis
Road equipment
Assessment of scheduling, equip condition
Vehicle/Implement design (as req'd)
Procurement
Transportation
Commissioning

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14. ABSTRACT
This report presents a consolidated airfield design for McMurdo, Antarctica. The design includes a single skiway for ski-equipped aircraft and a single runway for wheeled aircraft. Two possible locations for the new airfield are on glacial ice at the current Pegasus site or on a snow surface 4–5 miles NE of Pegasus. Final decision on the location requires balancing the need to locate the airfield outside the dust plume against the ability to establish on a snow surface a runway that supports wheeled aircraft. The current whiteout landing area would still serve the needs of the consolidated airfield; and Williams Field would continue to act as an emergency divert site for ski-equipped aircraft.

A review of the runway support facilities shows that the number of buildings can be reduced from 27 to 14, reducing the size of the town site and the travel distance between functional elements.

The consolidated airfield, including support equipment and facilities, will take about seven years to complete. When complete, it will improve operational efficiency by consolidating services at a single location, eliminating movement of resources between two or more airfields, and allowing replacement of existing runway support buildings with more energy- and space-efficient designs.

15. SUBJECT TERMS

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Energy efficiency	Ice foundation	Polar infrastructure
	McMurdo Antarctica	Snow foundation

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